USING THE FUNCTIONAL RESONANCE ANALYSIS METHOD (FRAM) TO MODEL AND ANALYZE LIFEBOAT TRAINING IN A SIMULATOR

By: Fatemeh Tavakoli

A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements of the degree of Master of Engineering

Faculty of Engineering and Applied Science

Memorial University of Newfoundland

January 2023

St. John’s, Newfoundland, Canada

ABSTRACT

Lifeboat operation is a complex procedure in which safety and rescue are of utmost importance. Training coxswain to perform these operations and acquiring sufficient skills and competencies to face unforeseen risks in harsh weather conditions is challenging. However, lifeboat simulators facilitate the training by removing the risk of training in real environments and improving training courses and trainees' skills.

In this study, a Functional Resonance Analysis Method (FRAM) model for launching a lifeboat and on-water tasks was created based on the approved lifeboat training course materials, rubric grading, and lifeboat course scenarios. Two scenarios were used to identify some essential functions in a lifeboat operation. Launch a lifeboat, get away from the platform and drive to a safe zone, pick up Person In Waters (PIWs), recover people from the life raft, tow a life raft, stop by a vessel and transfer the PIW are some tasks covered in this FRAM model. The model was tested with the simulator to identify variabilities in terms of accuracy and time. Five volunteers were asked to perform these scenarios. FRAM signatures of different performances were created to visualize various ways of doing an operation. Successful and unsuccessful operations were monitored using the FRAM, and key elements to having successful and unsuccessful outcomes were determined. Identifying functions and their variations helped to discover where and how trainees act differently in the lifeboat operation. The results of building the FRAM model showed that four categories of functions contributed to lifeboat operation, including action, assessment, decision-making, and skill. The comprehensive model presented in this study enables the researcher to better understand lifeboat operations and helps identify the variations that can affect an operation. Effective processes and key features to diagnose acceptable vs. unacceptable performance extracted by FRAM can be considered a perfect source of observational learning to

inform trainees. The FRAM approach used in this study can be employed to determine work practices that are more or less effective, allowing for the adaptation of processes and techniques to steer lifeboat training in the direction of routes that would provide better results.

ACKNOWLEDGMENTS

I would like to acknowledge and thank my supervisors, Dr. Doug Smith and Dr. Brian Veitch, for their devoted support, patience, motivation, and immense knowledge. I appreciate the direction and guidance provided during my graduate study and research work. Their wealth of knowledge and diverse backgrounds in the subject matter steered me through this research.

I would like to thank Virtual Marine (VM) for allowing me to work in a professional environment and using their high-tech lifeboat simulator for this research. I would like to thank Dr. Randy Billard and the staff of VM, who assisted in the research and supported me while I completed my studies. Also, the financial support from MITACS and VM is acknowledged with gratitude.

I would like to thank Dr. Vahid Salehi, Dr. Jennifer Smith, and my colleagues at the EN21111 office for their support and discussions.

I thank the financial support provided by NSERC-Husky Industrial Research Chair in Safety at Sea. Also, I would like to thank all the volunteers for the study. I appreciate their time and interest.

I also give thanks to my family and friends for their support and encouragement. Most of all, I would like to thank my father, Masoud Tavakoli, my mother, Montaha Fatahi, and my sisters for all their patience and continued support throughout the master's program, and always being there for me, thank you so much for everything.

TABLE OF CONTENTS

ABSTRACT i

ACKNOWLEDGMENTS iii

LIST OF TABLES vii

LIST OF FIGURES viii

LIST OF ABBREVIATIONS AND SYMBOLS x

1. Introduction 1

1.1 Background 1

1.2 Main Research Questions 4

2. Literature Review 5

2.1 Virtual Training 5

2.2 Lifeboat simulator 11

2.3 Adaptive training 16

2.4 FRAM 18

2.4.1 How to build a FRAM model in practice 20

2.4.2 Functional Signature 23

3. Methodology 25

3.1 Research design 25

3.2 Lifeboat simulator 27

3.3 Identifying and outlining essential functions 28

3.3.1 VM's coxswain training program 28
3.3.2 Scoring Rubric 28
3.3.3 VM's Lifeboat program scenarios 30
3.4 Building a conceptualized FRAM model 33
3.5 Testing model and learning from variations 34
3.6 Assess outcomes 34

4. Result 35
4.1 Identifying and explaining functions and building a conceptualized FRAM model 35
4.1.1 VM's coxswain training program 36
4.1.2 Scoring Rubric 38
4.1.3 VM's Lifeboat program scenarios 40
4.2 Testing model and learning from variations 43
4.3 Dynamic FRAM modeling 47
4.3.1 Successful and unsuccessful performance signatures 48

5. Discussion and recommendation 61
5.1 The capability of the FRAM for modeling the lifeboat operation 61
5.2 Monitoring the lifeboat operation by the FRAM 61
5.2.1 Acceptable and non-acceptable performance 62
5.2.2 The comprehensive FRAM model 65
5.3 Study limitations and future research 68

6. Conclusion 69

Reference 71

Appendices 79

Appendix I 79

FRAM model of the lifeboat operation 79

Functional descriptions and the initial description of the aspects of lifeboat operations 80

Appendix II 89

Videos of FRAM signatures 89

Appendix III 91

The comprehensive FRAM model of the lifeboat operation 91

LIST OF TABLES

Table 1. Training received by Group Designation(Billard et al., 2020a) 15

Table 2. Actual Lifeboat Specification (Billard, 2021) 27

Table 3. Scoring Rubric Categories (Billard & Smith, 2018)... 29

Table 4. Sample Grading Schema (Billard & Smith, 2018) 29

Table 5. Environment conditions.. 32

Table 6. Scenarios' Tasks.. 32

Table 7. Variability and possible consequences for launching a lifeboat.................................... 44

Table 8. Variability and possible consequences for on-water tasks 46

Table 9. Details of an unsuccessful performance of launching a lifeboat 49

Table 10. Details of successful performance of launching a lifeboat... 49

Table 11. Details of an unsuccessful performance of stopping by a vessel and transferring PIW 52

Table 12. Details of successful performance of stopping by a vessel and transferring PIW........ 53

Table 13. Details of the unsuccessful performance of picking up a PIW 56

Table 14. Details of the successful performance of picking up a PIW 57

Table 15. Acceptable and unacceptable performance for launching a lifeboat 62

Table 16. Acceptable and unacceptable performance for on-water tasks.................................... 64

LIST OF FIGURES

Figure 1. Desktop Lifeboat Simulator 13

Figure 2. Freefall Lifeboat Simulator 13

Figure 3. Davit Launch Lifeboat Simulator 14

Figure 4. The FRAM function diagram (Hollnagel, 2012) 21

Figure 5. An example of a simple FRAM model 23

Figure 6. The flow chart of this study 26

Figure 7. Lifeboat Simulator Interior and Lifeboat (Billard & Smith, 2018) 27

Figure 8. Emergency scenario (Billard et al., 2020b) 31

Figure 9. Basic FRAM model 36

Figure 10. FRAM model of launching a lifeboat (Based on the training course material) 37

Figure 11. FRAM model of on-water tasks (Based on the training course material) 38

Figure 12. FRAM model of launching a lifeboat (Based on the scoring rubrics) 39

Figure 13. FRAM model of on-water tasks (Based n the scoring rubrics) 40

Figure 14. Revised FRAM model of launching a lifeboat 41

Figure 15. Revised FRAM model of on-water tasks 42

Figure 16. FRAM model of the lifeboat operation 43

Figure 17. An example of an unsuccessful performance for launching a lifeboat 51

Figure 18. An example of successful performance of launching a lifeboat 51

Figure 19. An example of an unsuccessful performance of stopping by a vessel and transferring PIW 54

Figure 20. An example of successful performance of stopping by a vessel and transferring PIW 55
Figure 21. Difference between (a) unsuccessful and (b) successful performance........................ 56
Figure 22. An example of an unsuccessful performance of picking up a PIW 58
Figure 23. An example of successful performance of picking up a PIW 59
Figure 24. The comprehensive FRAM model of the lifeboat operation....................................... 66

LIST OF ABBREVIATIONS AND SYMBOLS

BN	Bayesian Network
CBT	computer-based training
CDF	Cumulative Distribution Function
CVNF	Canadian Virtual Naval Fleet
DNV-GL	Det Norske Veritas Germanischer Lloyd
ECC	Evacuation Control Center
EER	Evacuation, Escape, and Rescue
FMV	FRAM Model Visualizer
FRAM	Functional Resonance Analysis Method
FRC	Fast Rescue Craft
FT	Fault Tree
HPP	Human Performance Probability
IMO	International Maritime Organization
MOB	Man Overboard
MODU	Mobile Offshore Drilling Units
NeLCoE	Royal Canadian Navy eLearning Centre of Expertise
PIW	Person In Water
STAMP	System-Technical Accident Model and Process (STAMP),
STCW	Standards of Training, Certification, and Watchkeeping for Seafarers
SWOT	Strengths, Weaknesses, Opportunities, and Threats
VE	Virtual Environment
VM	Virtual Marine
VR	Virtual Reality
TEMPSC	Totally Enclosed Motor Propelled Survival Craft

1. Introduction

1.1 Background

Lifeboats are essential for safe functioning in maritime voyages and offshore operations. Launching a lifeboat is not a simple operation; it requires cooperation and synchronization of multiple roles, including that of the lifeboat operator, crew, and inspector. Their interactions affect the operation's outcome directly. In addition, training for emergencies is crucial for the coxswain. A lifeboat operator should be able to launch and maneuver a lifeboat in severe sea states as well as in severe weather conditions, e.g., snow, rain, darkness, and hazards. The sea state can be unpredictable, so before facing real-life danger, it is critical for coxswains to fully comprehend the launch procedure and get adequate training for maneuvering in hazardous situations.

Traditionally, trainees are expected to read training manuals before practicing in an actual launch scenario. Inexperienced operators are usually at risk in such scenarios. It may be difficult for beginners to understand a manual of a complex processes, especially when it involves multiple operators with different roles. Recent environmental changes, however, pose new and unique challenges to training, practice, and performance factors.

Skill acquisition can be improved by many factors, such as different training courses, the similarity of the practice environment to the actual situation, and the range and quality of training. Training courses for marine and offshore operations are usually conducted in calm water without any hazards to decrease the risk of danger. Offering training in such a safe environment might be challenging at the best of times, but there is limited or no actual training for high sea states or packed-ice conditions. Furthermore, little data is available on how abilities taught in lifeboat training transfer to different situations and harsh weather. Therefore, it is challenging to forecast human performance in emergencies. In this case, the trainee's performance in adverse weather and dangerous situations cannot be evaluated, and as a result, they may not be ready for an emergency evacuation. To fulfill this gap in training, a novel simulation-based training for marine evacuation systems was introduced by Veitch et al. (2008), which allows for training in harsh conditions while remaining safe.

A lifeboat simulator is a tool to put trainees in conditions similar to their operating site and test their abilities in emergency scenarios without facing actual hazards. The trainees' decision-making and mental models can be improved by exercising in a training environment with cues and stressors similar to a real emergency (Klein, 2008; McClernon et al., 2011). With the advancement of technology, marine simulation has become a growing field of study, paving the way for developing simulators for several marine scenarios.

This research aims to understand what criteria lead to a successful lifeboat operation and how to diagnose an acceptable performance from an unacceptable one. Data is collected from the simulator to explore how students behave differently in the same circumstance and discover activities requiring more training to achieve competence. Successful and unsuccessful operations will be tracked to better understand various functions that lead to different outcomes. For this purpose, it is important to determine what aspects of knowledge and skill are accessories to learning, evaluating possible situations and actions, and how feedback can be used to optimize student learning. However, in this study, only the student's model will be created, and an instructor's model can be discussed in further studies.

The Functional Resonance Analysis Method (FRAM) is proposed to be used as a basis for understanding the trainee's interaction with a lifeboat simulator. The method includes monitoring the performance of the activity for each operational case and understanding the process that produces each outcome (Smith et al., 2018). The FRAM allows visualizing complex work processes and dynamic conditions of the lifeboat operations (Hollnagel, 2012).

One of the challenges in training systems is that by traditional measurements, only the performance outcome is observable, and it is not always possible to observe the decision-making behaviors. One way to detect processing indicators relevant to decision-making and accumulate the desired level of training is the possibility of tracking and observing different behaviors of the trainees during the process. The FRAM is a technique to capture important functions and visualize a process.

In this research, a FRAM model of the lifeboat operation will be created, and different performances of successful and unsuccessful behavior will be tracked. In further research, the FRAM model of the instructors' feedback can add to the student's model to understand where and when an instructor can interrupt during a performance and develop the student's model.

The functional understanding acquired by applying the FRAM to the process can aid in determining key points in the scenario when a failure or success happens and how to do the assessment. Further, the generalized FRAM model can be used to diagnose errors across fundamental training principles by observing successful and unsuccessful performance, and as a result, trainee problems can be addressed immediately. The trainee's performance in these processes may be analyzed in real-time using updated measurements in these models. This can then be utilized to generate smart modifications that adapt the training system and can be used to offer a framework for autonomously assessing student performance in a lifeboat simulator in further studies.

1.2 Main Research Questions

For this research, the main research questions are:

1. What is the best way to model the functionality of a lifeboat operation and identify essential functions in the system?
2. How do trainees interact with a lifeboat simulator, and what aspects make differences between various performances?
3. What are the key points to diagnose acceptable vs. unacceptable performances?

2. Literature Review

2.1 Virtual Training

Practical training, along with science, has made significant progress in training courses in recent decades. Many parameters, such as up-to-date technologies, political, economic, and sociocultural issues, effectively force businesses to pay more attention to their training and human capital (Salas & Cannon-Bowers, 2001).

According to Spetalen & Sannerud (2015), simulations may be a practical approach to obtain a close transfer, provide context similarity, and link simulation activities and application context tasks. Virtual training offers several advantages and has been frequently used among industrial operators since the 1990s.

Some advantages which simulators provide are the ability to design specific simulation scenarios and training practices based on the trainees' needs and taking human factors into account. In addition, a well-planned training scheme combined with practice and implementation technologies that are simple to use and may be utilized by a broader range of students can be effective in providing prosperous training (Alamo & Ross, 2017).

Some benefits of using a simulator for training are lowering the chance of accidents during training, the ability to control scenarios and settings, providing training flexibility and repeatability, being cost-effective, and providing an immersive experience in standard operating procedures. Training in a virtual environment can be less time consuming compared to traditional methods, and it only depends upon the proficiency and speed of a trainee to achieve desired training goals. Since virtual training will accomplish training goals without experiencing a risky environment, its application is widely used in the military, medical, and firefighting fields (Alamo

& Ross, 2017; Gerlach et al., 2014; Kluge et al., 2014). Correcting errors and practicing new skills until achieving the required level for the task is another advantage of this type of training. Furthermore, it is not necessary to use the actual equipment resulting in saving up to 90% in costs (Babicz, 2003).

In virtual training, computerized models will be used to emulate various natural environments and hazards to achieve and develop different skills. Research by Perkins & Salomon (1992) indicates that simulator training, as a learning approach, accelerates the transfer of learning. This acceleration happens when learning in one environment or with one particular set of parameters affects performance in another setting or with other relevant sources. Bell et al. (2008) argued that a learner-centered outlook should be given more attention in future research on simulation improvement. Darken (2009) recommended designing training systems based on human performance. He believes that training technologies have improved a lot, and it is not reliable to base the training systems' design on traditional technology. Some researchers argued that similar language could be used to develop training systems. Therefore, by highlighting those approaches focusing on trainee performance, a new system can be built on top of them. Human-centric factors are also included in more recent studies, indicating their significant impact on the training (Håvold et al., 2015; Patle et al., 2014).

A user-center approach was used by Velez et al. (2013) when developing a training simulator to show the advantages of this method. Satisfactory results were obtained during the process, including increasing user expertise by trying different fields and exhaustive model assessment from various perspectives.

Taking into consideration the best learning method for training and how to retain new skills are the main structure of learning strategies based on a human-centric perspective. With learning strategies in place, a better sense of the simulator will be understood by the students and make it more user-friendly. Furthermore, during training, a better understanding will be gained through well-established learning strategies, and the trainee can retain information for longer (Marcano et al., 2019).

According to several studies, the superiority of one single characteristic might expedite learning transfer (Bailey & Witmer, 1994; Stevens & Kincaid, 2015). Some research has indicated that lower fidelity interfaces have higher training performance, and a better method could be to study the link between interface and training component (Cabral et al., 2005; Mania et al., 2004). The problem becomes determining which interface is most effective for a certain training goal (McMahan et al., 2012; Ragan et al., 2015).

Learning strategies and motivation awareness are two additional sub-themes in the human-centric perspective but are unfortunately being ignored most of the time. In the development of training courses, learning objectives, feedback processes, and assessment of training requirements are often overlooked and not prioritized effectively (Darken, 2009; Malakis & Kontogiannis, 2012).

Salas et al. (2012) support the "Transferring Appropriate Processing" and "Error Training" approaches. In the first approach, the expertise of a trainee will be increased by enhancing the difficulties at different levels, taking less advice and support from the instructor, and doing tasks that present the actual situation. Error training refers to the idea that making errors during the training presents the consequence of their action, leading to a deeper comprehension of training tasks and persuading them to try harder to learn. Therefore, to enhance their resilience and form their own strategies, trainees investigate the mistakes without the use of an instructor or help (Salas et al., 2006).

Conversely, receiving guidelines and instructor feedback will result in better performance in a shorter time. Hence, it can be concluded that self-correction and support correction are two sub-elements of error correction. Kluge et al. (2009), and Salas et al. (2006), argued that doing assessments as well as giving feedback are essential parts of developing a training system. Moreover, it can be beneficial to consider the individual training method to adapt a training system. Furthermore, organized and well-defined learning objectives should be considered for a training course, and trainees should be able to access relevant information.

Numbers that aid in measuring trainee performance, analyzing process status, and assessing if learning objectives have been met, are known as performance indicators. Marcano et al. (2019) state that it is important to define these indicators appropriately so they can be used to ensure that an evaluation process is targeted and repeatable.

Automatic assessment and feedback can be beneficial indeed when trainees receive a final assessment of their accomplishments, and they would be able to observe when or where they performed wrongly, learn from their mistakes and correct them for the next time. Additionally, their training progress and progression are trackable.

Marcano et al. (2019) indicated that considering operators' needs based on human-centric strategies in learning aspects and technical aspects, such as individual learning differences and using more user-friendly techniques can improve simulator training.

In addition, some instructors might not have enough confidence about bringing feedback up when a trainee is operating. That can be solved by implementing an automatic feedback system where they can decide what type of feedback to provide in real time. It can improve their confidence as well as motivate other export operators to become trainers (Marcano et al., 2019).

Moreover, instructors should have access to the database of the trainees' performance results to retrieve the outcomes, make assessments, track the operator's progress, and compare the records (Manca et al., 2012).

Some instructors believe that immediate advice should be provided through simulation tasks to enhance learning outcomes. At the same time, some ideas support bringing feedback up just after the simulation is done (Bell et al., 2008; Malakis & Kontogiannis, 2012).

Bell et al. (2008) believe effective feedback methodologies should be developed and embedded in simulator-based training. To support this idea, (Malakis & Kontogiannis, 2012) concluded that integrated instructional guidance would achieve more success in simulator training.

Manca et al. (2014) argued that automated feedback from automatic evaluation methods should be in place more regularly to boost students' motivation in simulator training.

Performing tasks under stressful and high-stakes conditions emphasize the importance of distinguishing between various training evaluation forms. Trainees should be ready enough to perform in a real environment where situations might be unpredictable and demanding, and this level of expertise should be in the characteristics of a training course to guarantee the development of trainees' skills to accomplish needed activities with high effectiveness and efficiency (Biswas et al., 2020).

Regarding the techniques for automated evaluation, Manca et al. (2012) suggested that procedures should be found based on objective and quantifiable criteria and the trainee be able to repeat them and get along with them.

Some research indicates that there are three stages for simulator training. First, there are no instructions, and trainees must rely on what they remember from the first practice. Second, the trainee will be examined for the task at hand in the absence of an instructor, and finally, guidance and feedback will be received by instructors gradually(Babicz, 2003).

Kinateder et al. (2014) used the Virtual Reality (VR) approach to analyze human behavior in fire. They made the assessment based on the Strengths, Weaknesses, Opportunities, and Threats (SWOT) technique and used various experiments completed in drills, laboratory settings, field and case studies. They argued that despite some weaknesses in using VR, such as ergonomic features, lower ecological reliability, and technological restrictions, it is a reliable tool to study human behaviors in fire and can be used to increase safety factors in this field.

Williams-Bell et al. (2015) reviewed different research to investigate whether virtual games and simulations can be practical and acceptable tools for firefighting training. They concluded that simulators could be used to develop some skills in firefighting and coordination of incident command. Still, game technologies are not good enough to be considered training tools as they cannot present accurate and complete real-world scenarios.

Kobes et al. (2010) compared human behaviors in fire evacuation results in an actual building vs. a virtual environment. Pre-movement and movement times, pre-evacuation and evacuation behaviors, as well as route decisions were tracked and considered for the analysis. Three scenarios were considered for this experiment: blocking the main exit with smoke, a fire drill simulation, and the last scenario was blocking the main exit where the exit signs were put on the ground level. Results indicated that in the two first scenarios, the differences between the real and simulated environments were not noticeable. For the third scenario, however, there were different approaches to choosing the exit route. It can be concluded that a Virtual Environment (VE) is promising enough for use as a tool to analyze way-finding performance.

Simulator-based training is popular in other industries as well. A study about using the simulator for driving has shown that some forms of training can induce cognitive changes with the potential to improve driving ability. However, detecting such advantages is challenging due to the problems encountered in defining and measuring driving competency. Also, sometimes lack of realism with actual driving can cause simulator sickness, especially in older persons (Roenker et al., 2003).

Magee (2012) developed a study at Royal Canadian Navy eLearning Centre of Expertise (NeLCoE) to investigate the effect of using simulators as a training method for navy submarine operations. Canadian Virtual Naval Fleet (CVNF) was used to conduct different experiments. A group of novice people was trained in VE and then asked to do drill operations in a real environment. In the first stage of this experiment, the results were compared to the experienced personals' performance. It was concluded that people trained by the simulator needed more time to complete each task. In the second part, the performance of novice trainees who were trained in the VE did a better job than those trained by traditional methods. Results showed the superiority of using a virtual environment over the traditional level because VE can demonstrate a higher level of spatial knowledge, and it increases the quality of the training.

2.2 Lifeboat simulator

Qualified seafarer education and training are mandatory based on the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) (STCW, 2011). An appropriate response to the complex advanced technologies that mariners encounter onboard ships is implementing full-mission bridge simulators (Emad & Roth, 2008).

Gaining skills in a variety of marine tasks, such as berthing, navigation, and maneuvering in a safe and comfortable environment, is achievable by using simulators. Recent research, however, emphasizes the need to improve the reliability of the data of performance assessment methodologies for marine navigation (Ernstsen & Nazir, 2018). In this case, using a dependable and valid evaluation instrument in marine simulator training, such as computer-assisted assessment methods, can be effective (Ernstsen & Nazir, 2020).

VR is useful in various training contexts in marine operations. Some simulation-based training systems are intelligent and adjustable, and the training course can update constantly based on the trainee's learning condition. However, most of those pieces of training are not adaptable to the trainee's real-time cognitive or subjectively experienced load (Dey et al., 2019).

Tracking user performance is important in developing the training content in an adaptive simulation-based training system. VR training gets harder or easier depending on whether the user completes a task properly or incorrectly (Dey et al., 2019).

The lifeboat simulator is a beneficial tool to train coxswain in every aspect of launch and maneuvering a lifeboat. Lifeboat simulators are based on VR technology, enabling trainees to be trained in any situation and circumstance(Morild Interaktive, 2017).

Because of some capabilities of this simulator, such as having actual equipment (i.e., compass, throttle, and steering wheel), simulating lifeboat motion and equipment, and representing the real environment and situation, trainees are able to experience learning in a situation close to the actual working environment.

Figure 1-Figure 3 present different lifeboat simulators developed by VM (Virtual Marine, 2022). Each simulator can be used depending on the scenarios and requirements for the training course.

Figure 1. Desktop Lifeboat Simulator (Virtual Marine, 2022)

Figure 2. Freefall Lifeboat Simulator (Virtual Marine, 2022)

Figure 3. Davit Launch Lifeboat Simulator (Virtual Marine, 2022)

Billard et al. (2021) indicated that trainees' proficiency in launching a lifeboat could be affected by any changes in the environmental condition even though they were experts during the training. Van Merriënboer et al. (2002) concluded that trainees' concentration would be increased by adding more variability in the training course, resulting in better training transfer to new scenarios. On the contrary, some researchers have argued that the quantity of practice or the structure of the learning system is more essential than diversity in exercise (Van Rossum, 1990).

Studying performance on cognitive tasks related to launching a lifeboat showed that practicing in progressive situations with exposure to various weather conditions and risks improves performance during launch tasks incrementally; however, some skills may fade (Stewart et al., 2008). In the case of maneuvering tasks, the amount of training time in calm water conditions or lower sea states needs to be increased to achieve better performance in moderate water. A lifeboat's poor performance at low speeds might decrease the success rate (Billard et al., 2020a).

This research indicates that the type, amount, and frequency of training are not the only main factors, and some skills may not be achieved in practice.

The results of training coxswains who trained by three different methods over a year were analyzed by Billard et al. (2020a) The first group was trained with a lifeboat in a real environment. A Computer-Based Training (CBT) method was used for the second group, and the last group did the training in a simulator. Different practical practices were considered for each group to see the effect of each item in training (Table 1).

Table 1. Training received by Group Designation (Billard et al., 2020a)

Group	Representative Training Practice	Launch Tasks	Maneuvering Tasks	Scenario Parameters	Faults and Hazards
Group 1 - Drills	Live offshore quarterly drills from an offshore platform	Practiced in simulator with real lifeboat equipment	Practiced on water using real boat	Same scenario each training session, limited to calm waters,	None
Group 2 - CBT	Annual refresher training with skills maintained quarterly through self-study	Desktop CBT based on operating manuals	Desktop CBT based on operating manuals	N/A – no scenario practice used	Covered in CBT
Group 3 - Simulator	Simulation based training programs in use in Oil and Gas Training	Practiced in simulator with real lifeboat equipment	Practiced in simulator with real lifeboat equipment	Progressive with each training session, calm to moderate sea state	Introduced as scenarios progressed

The results from these experiments indicated that the success rate in both launching and maneuvering a lifeboat was low. It showed the superior performance of drills and simulator bodies over the CBT team. Billard et al. (2020a) argued that having maritime education and realistic lifeboat controls to practice difficult and complex scenarios close to the real environment can improve the training outcome.

Billard et al. (2020) developed the Human Performance Probability (HPP) to define how a trainee can successfully complete a task in a lifeboat scenario. The objective was to generate probability distributions using data from a lifeboat simulator to analyze new trainees' skills gained when they attend a training program intended to prepare coxswains for offshore situations. Bayesian inference was conducted to use collected data from the simulator in order to revise former knowledge about HPPs of lifeboat coxswains. The result shows that the original training program did not result in a high group performance on their first try at tasks in a real emergency scenario. The predicted chance of completing most activities successfully is less than 50%, implying that most volunteers will fail to accomplish the launch and maneuvering tasks on their first try. Overall, the chances of the coxswains completing all scenario duties in the correct order, as required in an actual lifeboat evacuation, were slim. Most tasks had a high chance of being completed successfully with more practice. Based on HPP Cumulative Distribution Functions (CDFs), the tasks of launching a lifeboat and picking up a Person In Water (PIW) require more practice than other tasks.

2.3 Adaptive training

Three factors should be considered to evaluate a simulator-based training course: whether students attained the desired level of competence; if they performed the correct steps to reach the final product; and if the simulator functions as intended. For this kind of assessment, performance yields more process data vs. product data (de Klerk et al., 2015a).

Understanding the assessment purpose is necessary for knowing what aspects are critical and what types of claims are involved in performing well on the assessment. Answering some questions such as what parameters are important in a situation, why something just happened, and what is the next step to do can help trainees build their knowledge structure (Mislevy, 2011). Generally, the evaluation process consists of diagnostic and evaluation phases. Adapting the training course, improving the structural model, and implementing the developed model are the main part of the assessment process (Millán & Pérez-De-La-Cruz, 2002).

Park and Lee (2013) state that adaptive training methods are *"...educational interventions aimed at effectively accommodating individual differences in students while helping each student develop the knowledge and skills required to learn a new task."* This conceptualizes how to employ some instructors to provide the best possible learning experience for each trainee.

By considering an adaptive training system, trainees' needs and characteristics will be adjusted by the training content. Furthermore, the trainee's performance can be reflected in each task. In the meantime, training performance and trainees' aptitude can adjust by training interventions. In addition, to give students an optimal learning experience, it may be necessary to manipulate the instruction's features. As a result, the training intervention might be more effective (Graf, 2014; Landsberg et al., 2010).

However, determining which factor and combination would be more effective in an adaptive training system has been argued by researchers (Park & Lee, 2013). Kelley (1969) indicated that it is critical to select a reliable measurement to guarantee that proper adaptation (of difficulty, concepts, or material) is applied to the trainee.

Landsberg et al. (2012) argued that presenting variables such as errors, emotional/psychological states, and test scores to reflect a trainee's performance during a training course resulted in better scores than receiving a number of fixed concepts. On the other hand, the type of instruction or how to employ the instructional interventions will be important (Tennyson & Rothen, 1977).

2.4 FRAM

Safety management should focus on how to increase the success in a system rather than finding errors to decrease the failure in the system. This viewpoint, referred to as Safety-II, focuses on the system's variability in various circumstances. *"Safety-II approach assumes that everyday performance variability provides the adaptations that are needed to respond to varying conditions, and hence is the reason why things go right"* (Hollnagel et al., 2015). The success of a system under varying conditions is discussed in the Safety-II perspective. According to this approach, performance modifications or adaptations are needed to adjust to various circumstances(Hollnagel, 2018). The FRAM is a Safety II method that facilitates understanding complex socio-technical systems that aid in safety and risk management by modeling functionality (Hollnagel, 2012).

The FRAM is based on visualizing complex socio-technical systems. It is a method for structuring a system that involves recording the many ways the system might operate to create different outputs and mapping its functioning (Smith et al., 2018).

In the FRAM, unacceptable outcomes, like accidents, will be considered emergent and frequently include more than just human error or defective parts. In other words, the interactions between variables, inputs, and outputs and also causes and effects result in the emergence of both desired and unanticipated outcomes. As a result, the FRAM tends to study the dynamics in such systems.

Instead of focusing on physical elements, it stresses essential features, complex interrelationships, and operational variance (Hollnagel, 2012; Salehi, Veitch, et al., 2021). The FRAM is based on four principles:

1. **The equivalence of successes and failures:** It means that failure and success in a system happen in the same way, and the capacity of companies, communities, and people to adapt successfully to expected and unforeseen conditions determine both acceptable and unsatisfactory results. In other words, because the results are different doesn't necessitate that the reasons are likewise different (Hollnagel, 2012).
2. **Approximate adjustment:** A system must constantly adapt to the current circumstances (materials, time, tools, information, etc.) since operations and environments are never fully stated. In addition, due to the uncertainty and finite nature of additional resources such as time, materials, knowledge, opportunities, etc., the modifications will often be approximate rather than exact (Hollnagel, 2012).
3. **Emergent outcomes:** According to the third principle, acceptable and undesirable results may be explained as emergent from variability driven by routine changes rather than from a single or a series of cause-and-effect relationships arising from the breakdown or error of a particular component or part (Hollnagel, 2012).
4. **Functional resonance:** Similar to the resonance concept, one variability in the system is not strong enough to be considered the root cause of a system failure. Based on the fourth principle, the aggregation of weak variabilities of some functions can intensify other tasks' variabilities in the system, boosting the entire system variability (Hollnagel, 2012).

2.4.1 How to build a FRAM model in practice

Assessing complex socio-technical systems using the FRAM is done in four stages (Hollnagel, 2012; Salehi, Veitch, et al., 2021):

(a) Identifying and outlining essential functions

(b) Describing the prospective variability of each detected function

(c) Considering the potential of functional resonance based on dependencies or couplings

The first step of FRAM focuses on mapping the activities for an operation that is being investigated. A lens of "functionality" is used to model the work that is done by technologies and humans in a common framework. A function node represents each action or function that takes place during the process. There are six components for each functional node: input, output, time, control, precondition, and resource (Hollnagel, 2012). This is depicted in Figure 4.

- Input: input is what can activate a function and produce the outcome in terms of information, energy, material, or some form of data.

- Output: any function needs to have one outcome(s) or result(s) that shows work has been done. The output then can be as input, resource, precondition, or other aspects for another function(s).

- Precondition: before a function starts, it might need to check the system state, verify some conditions, and establish some preconditions. The main difference between precondition and input is that preconditions cannot start a function.

- Resource: sometimes, when a function is running, some resources in terms of energy, tools, competence, etc., need to be consumed. Resources that are not consumable, such as hardware, will be known as execution conditions and are not the focus of this research.

- Control: To have the desired outcome, a function might need to be regulated or controlled by some procedure, instructions, plans, etc.

- Time: functions can be affected by the time to describe when they are carried out, whether they are parallel to other functions or completed before or after other functions.

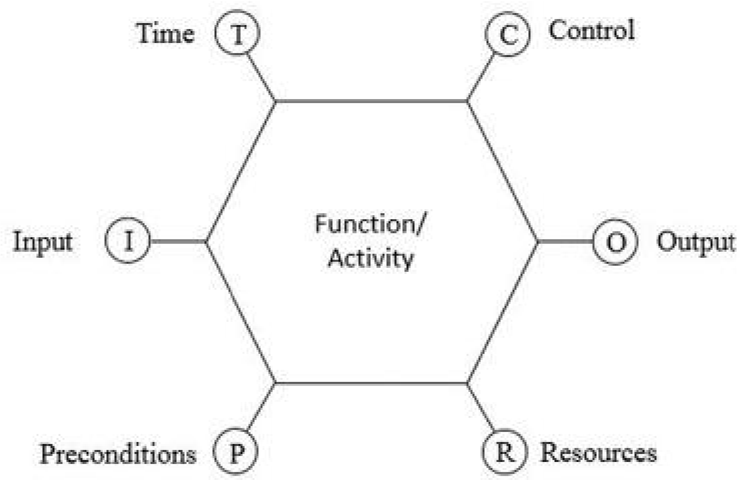


Figure 4. The FRAM function diagram (Hollnagel, 2012)

All aspects should be considered in a FRAM model but not all of them will be significant to the functional execution of each function. By examining each function's output and following the path it takes to reach a downstream function, linkages between the functions may be built. A map of all the activities and their relationships in the operation will be created after this is accomplished for all of the process's functions.

Background and foreground functions are the two categories of a function used in the FRAM work. Background functions can be considered constant when analyzing the structure as they only have inputs or outputs, while at least two active functions should consider for the foreground functions (Hollnagel, 2012).

The FRAM's second goal is to describe the system's variability. A subset of that range of functionality may be used each time the process is performed. Once its potential components have been determined, it is important to explain the variability. At the same time, the original FRAM model should explain all (or many) conceivable ways the process may operate (the third step). In other words, not every function in the model must be performed, or run in a specific manner, to result in an outcome. The outcome will differ as well; in fact, differences in the functional execution might be used to explain variances in the end result. This includes many outcomes that can range from bad to good (Hollnagel, 2012; Smith et al., 2020). The last step includes recommendations seeking to determine safety barriers.

An example of a simple FRAM model is presented in Figure 5. It is meant to assist in understanding the ideas about the FRAM, though it is not an actual model. There are six functions in this model. Here, B is a background function, and C is a foreground function. A coupling can be observed between B and C; however, there is no connection between B and D (Salehi, Veitch, et al., 2021). FMV (FRAM Model Visualizer) software developed by Hill & Hollnagel (2016) has been used to model the FRAM to map complex socio-technical systems.

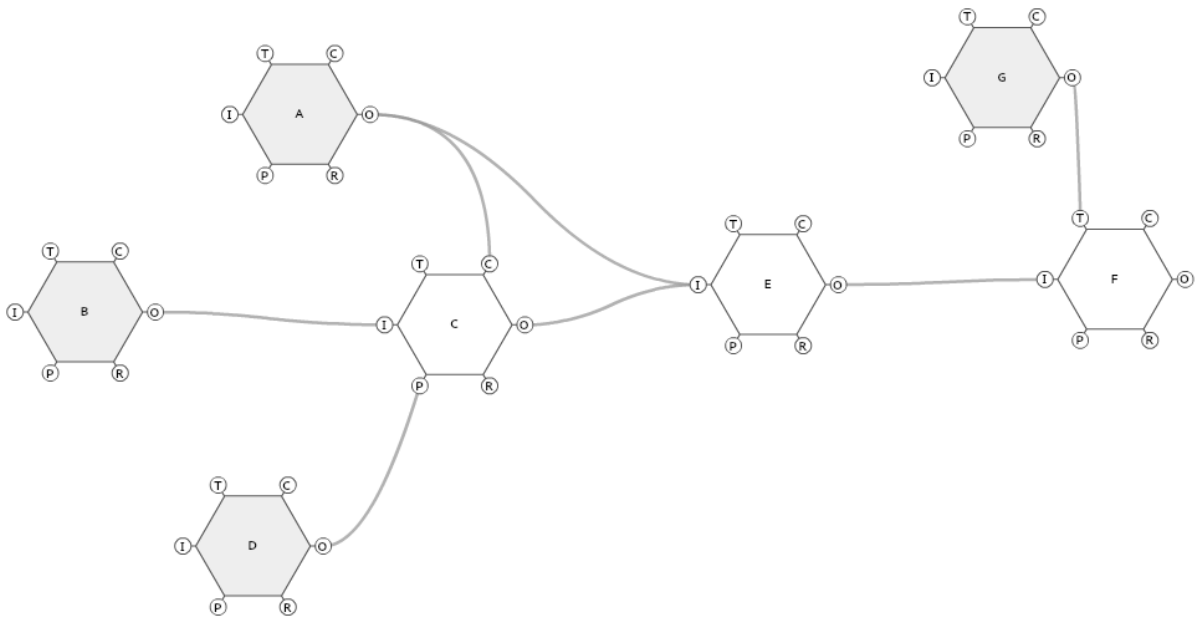


Figure 5. An example of a simple FRAM model

2.4.2 Functional Signature

Functional signature is a development of the FRAM technique that enables us to track different performances. A functional signature that is unique to each measurement captures the functional dynamic. When a large number of performance measurements and functional signatures are collected, it is possible to compare signatures that produce different levels of performance (Smith et al., 2018). The FRAM is a method to determine the possible pathways of successful and unsuccessful operations. Understanding how a system achieved success or failure can be done by capturing performance variability, including 1. Capturing qualitative characteristics of variability for the output(s) of functions and the entire system's outcome, 2. Capturing the quantitative characteristics of variability, and 3. Capturing temporal variability when time variation impacts the functional output(s) and the outcome of the entire system (Salehi, Smith, et al., 2021).

Each signature presents variabilities in the system. Aggregation of variabilities resulted in good and poor performance. Based on these results, the trainer can promote practices that lead to high performance and remove practices associated with poor performance.

A dynamic FRAM-based tool developed by Salehi et al. (2021) is used in this research to capture the functional signature of trainees. The DynaFRAM tool enables the recording and visualization of changes that occur in both the results of operations and the overall system's outcome of the decision. The DynaFRAM's increased flexibility for users to create scenarios and capture temporal fluctuations in both function outputs and the outcome(s) of the overall system. It can be used to capture individual trainee performance for each scenario. The FRAM approach used in this study can be employed to determine work practices that are more or less effective, allowing for the adaptation of processes and techniques to steer lifeboat training in the direction of routes that would provide better results.

3. Methodology

3.1 Research design

In this research, a FRAM model for launching a lifeboat and on-water tasks will be created to model the functionality of a lifeboat operation and extract essential functions in the system based on the approved lifeboat training course materials developed by VM, scoring rubrics, and two sample scenarios. Then, the model will be examined by practicing in the simulator, and different performance variabilities will be identified. Furthermore, FRAM signatures will be extracted by monitoring successful and unsuccessful performances to identify how trainees interact with a lifeboat simulator and what features make differences between various performances. Finally, information from different FRAM signatures will be used to diagnose an acceptable vs. an unacceptable performance. Figure 6 encompasses a flow chart of what will be carried out in this research. The hypothesis for this research is that the lifeboat simulator used in this study would be a valuable tool for knowledge capture and testing a FRAM model. Monitoring good, bad, expert, and novice performances would allow for classifying different approaches and identifying the relationships between successful and unsuccessful operations. Finally, effective processes and key features extracted by the FRAM will be a source of observational learning to inform trainees.

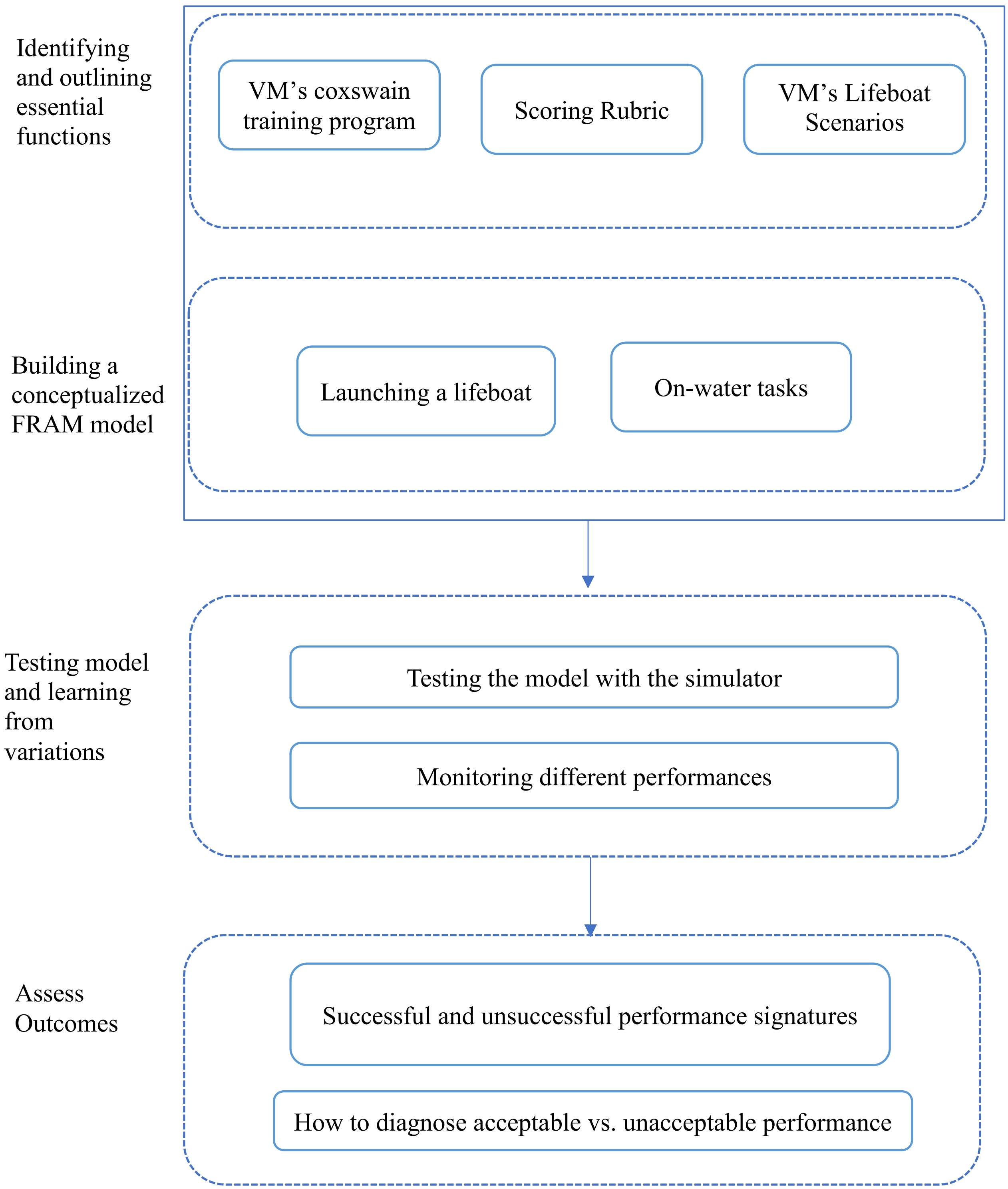


Figure 6. The flow chart of this study

3.2 Lifeboat simulator

A lifeboat simulator developed by VM has been used for this research. Transport Canada and Det Norske Veritas Germanischer Lloyd (DNV-GL) certified the lifeboat simulator. Also, it is recognized by the International Maritime Organization (IMO) STCW and Mobile Offshore Drilling Units (MODU) codes. Figure 7 shows the same type of lifeboat is used for offshore platforms in the North Atlantic (Billard & Smith, 2018). Table 2 shows some specifications of the Totally Enclosed Motor Propelled Survival Craft (TEMPSC).

Figure 7. Lifeboat Simulator Interior and Lifeboat (Billard & Smith, 2018)

Table 2. Actual Lifeboat Specification (Billard et al., 2020a)

Capacity	Length (m)	Width(m)	Depth(m)	Draft(m)	Lightweight(kg)	Dead weight(kg)
72 person	9.4	3.5	6	2.9	5,806	11,500

3.3 Identifying and outlining essential functions

3.3.1 VM’s coxswain training program

In order to have a better understanding of the lifeboat simulator and training course, the writer passed the VM’s Lifeboat training program. This course consists of five modules, including 1. Course introduction 2. Lifeboat system 3. Launch and release 4. Clear away and operation, and 5. Survival and rescue. After finishing the theoretical sections, there are some practices to familiarize with the simulator, and finally, there are some scenarios that trainees need to complete to finish the course. The material in this course was used to identify some critical functions for launching and maneuvering a lifeboat to create the initial FRAM model.

3.3.2 Scoring Rubric

Billard & Smith (2018), conducted research to assess trainees' performance in the simulator based on: 1. Live instructors and 2. An automated simulator. For launching and on-water tasks, a scoring rubric was developed in order to identify quantitative measures (Table 3). Each task was quantified using subtask measurements to create an accurate performance indicator that a live trainer and simulator could assess. Based on each task, different measures were taken.

Furthermore, measuring performance takes additional aspects into account as tasks become difficult. This rubric consists of three parts: Launch performance, Navigation tasks, and On-water tasks. Each piece considered different objectives, and mostly for each goal, various criteria were defined to label each performance as incomplete (Failure), Acceptable (novice), or complete without difficulty (Expert).

Table 3. Scoring Rubric Categories (Billard & Smith, 2018)

Task	Objective
Launch Performance	Lower w/o stopping (Y/N), Engine started prior to splash down, air and deluge, of re-entries, Splashdown zone, Contact with the platform, Clear away zone, Exclusion/danger zone
Navigation Tasks	Navigate to a landmark, Navigate using a Compass, Stop in a safe zone, Rig for Survival (Sea anchor)
Boat Handling Task	Hold station near a drifting object, Approach a fixed mark, Stop at a fixed mark, Approach a drifting vessel, Come alongside a drifting vessel, Approach a fixed vessel, Come alongside a fixed vessel, Pace a rescue vessel for painter hook-up / Passenger transfer, Approach a PIW, Recover a PIW,

The evaluation criteria determined performance based on quantitative factors such as distance to objects, task completion time, vessel speed, and direction. A sample of rubric scoring is provided in Table 4. This scoring rubric was used to revise the FRAM model. In addition, some criteria in this section were considered to diagnose a good performance vs. a bad performance. It should be noted that these scoring rubrics are not used in the simulator evaluation.

Table 4. Sample Grading Schema (Billard & Smith, 2018)

Task	1 Point - Failure	3 Point - Acceptable	5 Points - Expert
Recover a PIW	• Was unable to recover a PIW on first attempt or hold position	• Was able to recover a PIW on first attempt	• Was able to recover a PIW on first attempt

	• Could not reduce speed • Contact made with PIW • Approached from upwind and drifted down to the PIW	• Stopped within 2.5m of the PIW from the side hatch for a minimum of 10 seconds or more • Slowed to within 0.5 - 1 knot • No contact with PIW • Approached from abeam to the wind • Stopped with the bow pointed off of the wind	• Stopped within 2.5m of the PIW from the side hatch for a minimum of 10 seconds • Came to a complete stop (speed > 0.5 knots) • No contact with PIW • Approached from downwind • Stopped with the bow pointed towards the wind

3.3.3 VM's Lifeboat program scenarios

This research intends to focus on lifeboat training. VM's lifeboat training program has several modules and practice scenarios. A similar scenario is shown in Figure 8 (Billard et al., 2020b). Environmental conditions in the scenario are: 3-meter waves; Fire hazards; Night time; and Leeward launch. The tasks to do are: 1. Launch a lifeboat; 2. Investigate life raft; 3. Recover PIW's; 4. Transfer PIW's to Fast Rescue Craft (FRC); and 5. Navigate to the safe zone.

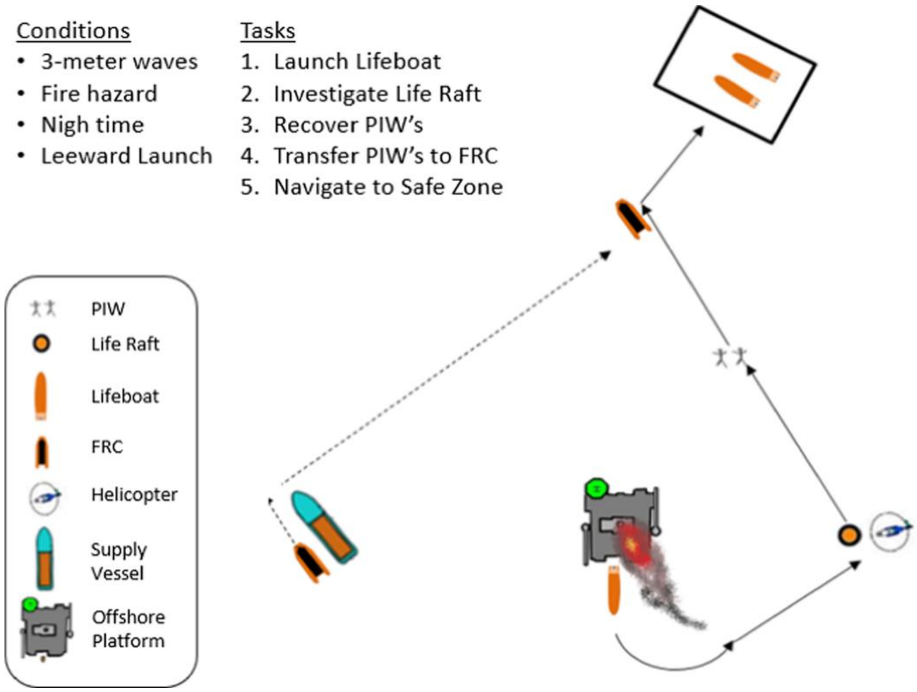


Figure 8. Emergency scenario (Billard et al., 2020b)

There are many scenarios for a training course, and modeling all of the practical functions can be difficult to track and makes the FRAM model so complicated. In this regard, only two scenarios developed by VM were considered, covering the most critical objectives for a safe lifeboat operation, such as launching a lifeboat, picking up a PIW, approaching a life raft, and stopping by a vessel.

The first scenario is the lifeboat drill. The mission in this scenario is to launch the lifeboat and clear away to the safe zone. Trainees must complete tasks including launching a lifeboat safely and driving to the safe zone, PIW, towing a life raft, stopping by a vessel, and transferring PIW to the recovery vessel, and finally, deploying the sea anchor.

The second scenario is about an emergency lifeboat launch and complex maneuvering exercise. The mission in this scenario is launching a lifeboat in high sea states, picking up 2 PIWs, rescuing the life raft survivors, stopping at the nearby platform, and finally deploying the sea anchor in the safe zone. Weather conditions and tasks for both scenarios are listed in Table 5 and

Table 6. At the end of the scenario, the volunteer's performance will be assessed based on the pass/fail grading system.

Table 5. Environment conditions

Environmental condition	Scenario 1	Scenario 2
Sea State:	Ripples	Small Waves
Current:	Slack	Slack
Platform Heading:	Northeast	East
Launch Type:	Leeward	Windward
Weather:	Sunny	Overcast
Wind:	Northeast, Light Air	East, Moderate Breeze
Visibility:	Clear	Reduced

Table 6. Scenarios' tasks

Scenario 1	Scenario 2
1. Launch 2. Clear away 3. Pick up PIW 4. Tow life raft 5. Stop by the recovery vessel and transfer PIW 6. Deploy sea anchor	1. Launch 2. Clear away 3. Pick up 2 PIWs 4. Rescue raft survivors 5. Steer compass course to the nearby platform 6. Deploy sea anchor in the safe zone

3.4 Building a conceptualized FRAM model

The FRAM model in this research consists of two parts: launching a lifeboat, and maneuvering in the water. To avoid complexity, the FRAM model was built in a way to cover both scenarios. The first task for evacuating from an offshore platform is to launch the lifeboat. The main functions of the launching part are: to establish communication with the Evacuation Control Center (ECC), start the engine, pull and hold the brake release cable, release the safety pin, release the hook, move the throttle, and drive away to the safe zone.

In the case of on-water tasks, missions are variable based on the objectives for each scenario. The first scenario's main objectives are picking up one PIW, towing a life raft, transferring the Man Overboard (MOB) to the recovery vessel, and deploying the sea anchor. The second scenario consists of picking up 2 PIWs that are close to each other, recovering people from the life raft, navigating to the safe zone, and deploying the sea anchor. Finally, launching a lifeboat and maneuvering in the water were combined in one FRAM model.

In order to build a FRAM model, the first step is to consider the main functions and their aspects. The training material, grading rubrics, and lifeboat course scenarios developed by VM were used to identify these functions. The second step is to recognize the functional variabilities and assess how dynamic conditions are effective in creating different outcomes. The final step is to analyze how coupled variety changes a system's performance.

3.5 Testing the model and learning from variations

A FRAM model can be utilized to examine how different functions in the system can be influenced by the variation and modifications of one function, and if it can change the result in the overall activity (Hollnagel, 2012).

In this regard, the FRAM model for the launching and on-water tasks was tested in the simulator for two purposes: 1. Validate the FRAM model, 2. Identify functional variabilities in the system.

In addition, five volunteers were asked to perform these two scenarios to monitor different performances. Among them were people who had experience with the simulator, experience with the actual lifeboat, or novice people who had just passed the Advanced Coxswain Training course.

3.6 Assess outcomes

Signatures for successful and unsuccessful performances for different tasks will be created based on these volunteers' samples to show different ways of doing an operation and what can make a difference during a performance. The DynaFRAM will be used to create signatures. Finally, key points to diagnose successful vs. unsuccessful performance will be extracted from signatures based on criteria in the scoring rubric.

4. Results

4.1 Identifying and explaining functions and building a conceptualized FRAM model

To start a FRAM model, imagine that "Establishing communication with ECC” is the first function in this operation. To start any scenario, trainees have to have permission from ECC to go ahead with the mission. Before and after any operation, they need to make "communication with ECC" to understand the next objective and details about it and report their performance after they finish a task. That shows how important this function is and will be repeated several times in any scenario. Before issuing permission from ECC, the student cannot start the following function, "Pull and hold brake release cable." Therefore, "Establish communication with ECC " is an input function for "Pull and hold brake release cable." However, before pulling the cable, the trainee must start the engine. As a result, "Start the engine" is a precondition for "Pull and hold brake release cable." While pulling the cable, the trainee should "lower the cable without stopping" and "check the hydrostatic indicator" until the lifeboat is in the water. In this regard, "Lower without stopping" and "Check the hydrostatic indicator" are two control functions for this objective. As soon as the lifeboat is in the water, the safety pin should be released; as a result, "Pull and hold brake release" can be considered as an input for "Release the safety pin" (Figure 9). This approach will continue until all necessary functions with their aspects are identified.

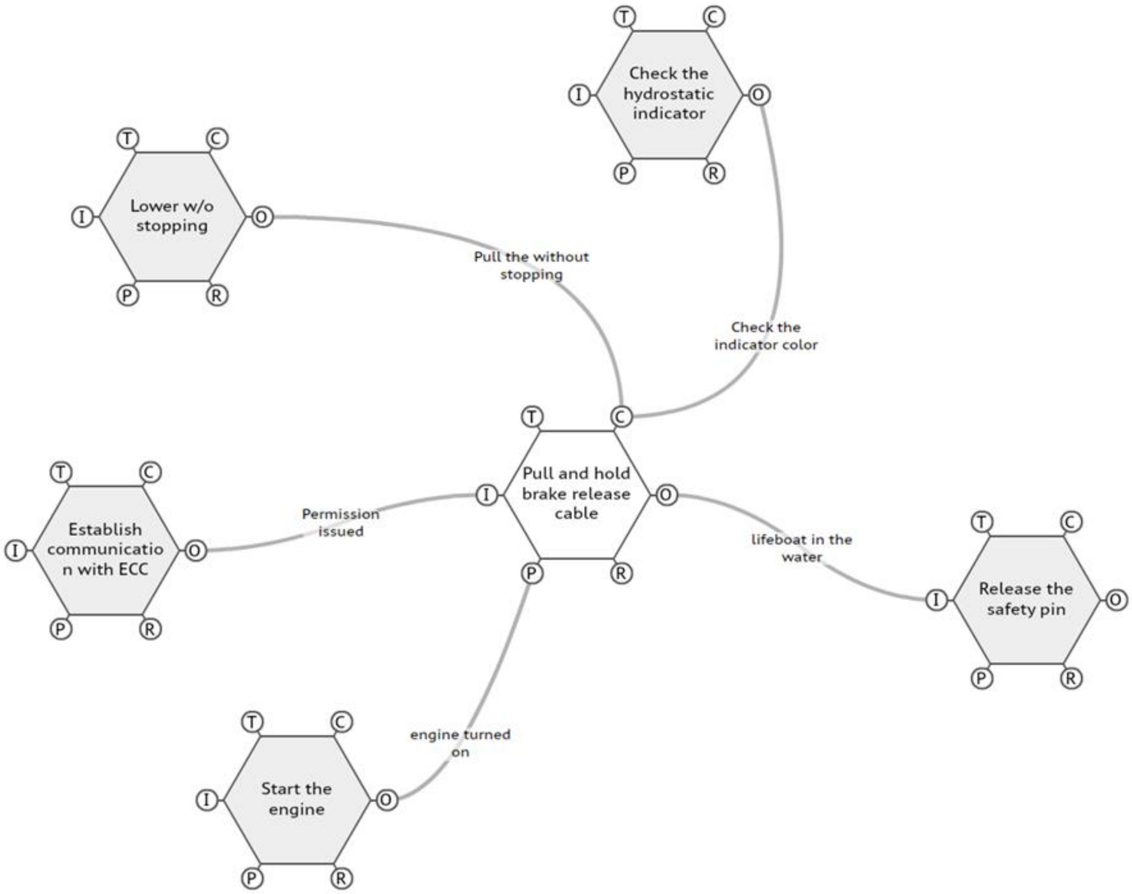


Figure 9. Basic FRAM model

4.1.1 VM's Coxswain training program

The first FRAMs for launching and on-water tasks were created based on the approved lifeboat training course developed by VM. This course consists of five modules, including: 1. Course introduction; 2. Lifeboat system; 3. Launch and release; 4. Clear away and operation; and 5. Survival and rescue.

Figure 10 shows the FRAM model of launching a lifeboat. Data used to create this model is mainly from modules 2 (Lifeboat system), 3 (Launch and release), and some parts of module 4 (Clear away and operation).

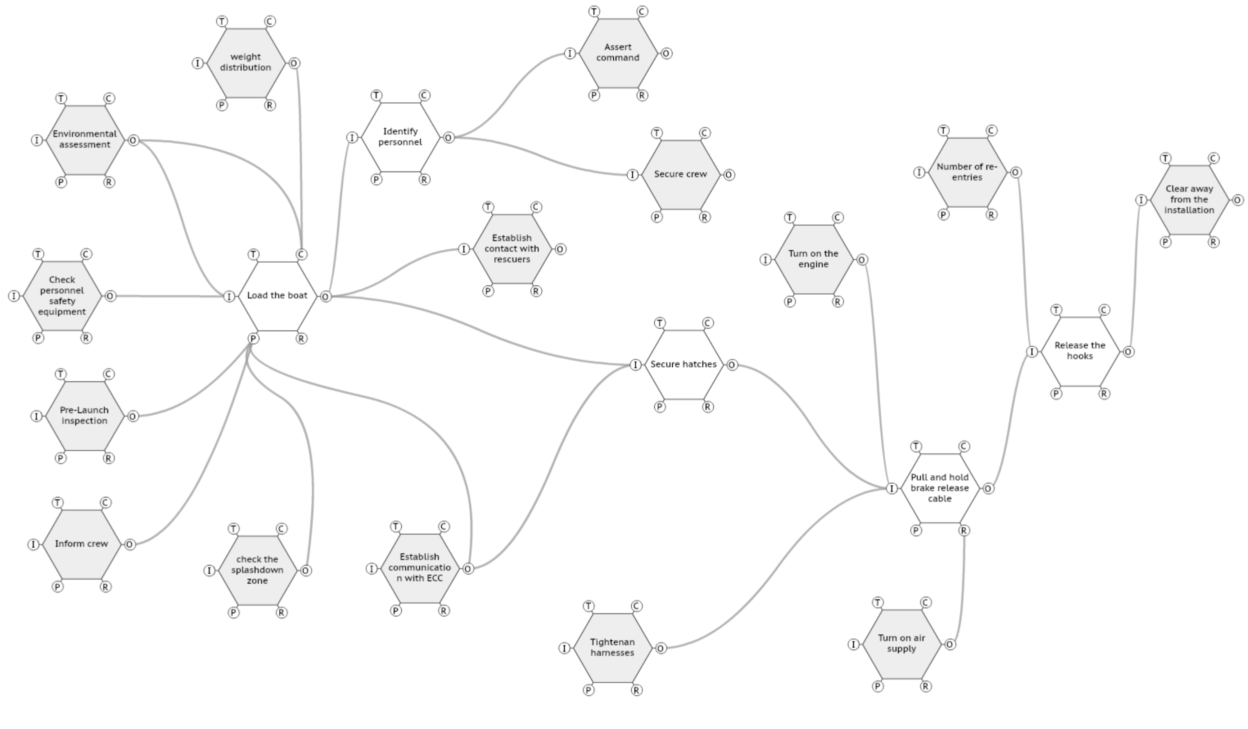


Figure 10. FRAM model of launching a lifeboat (Based on the training course material)

In order to build the FRAM model of on-water tasks and identify main functions, modules 4 and 5 (Clear away and operation and survival and rescue) from VM's lifeboat training course were used (Figure 11).

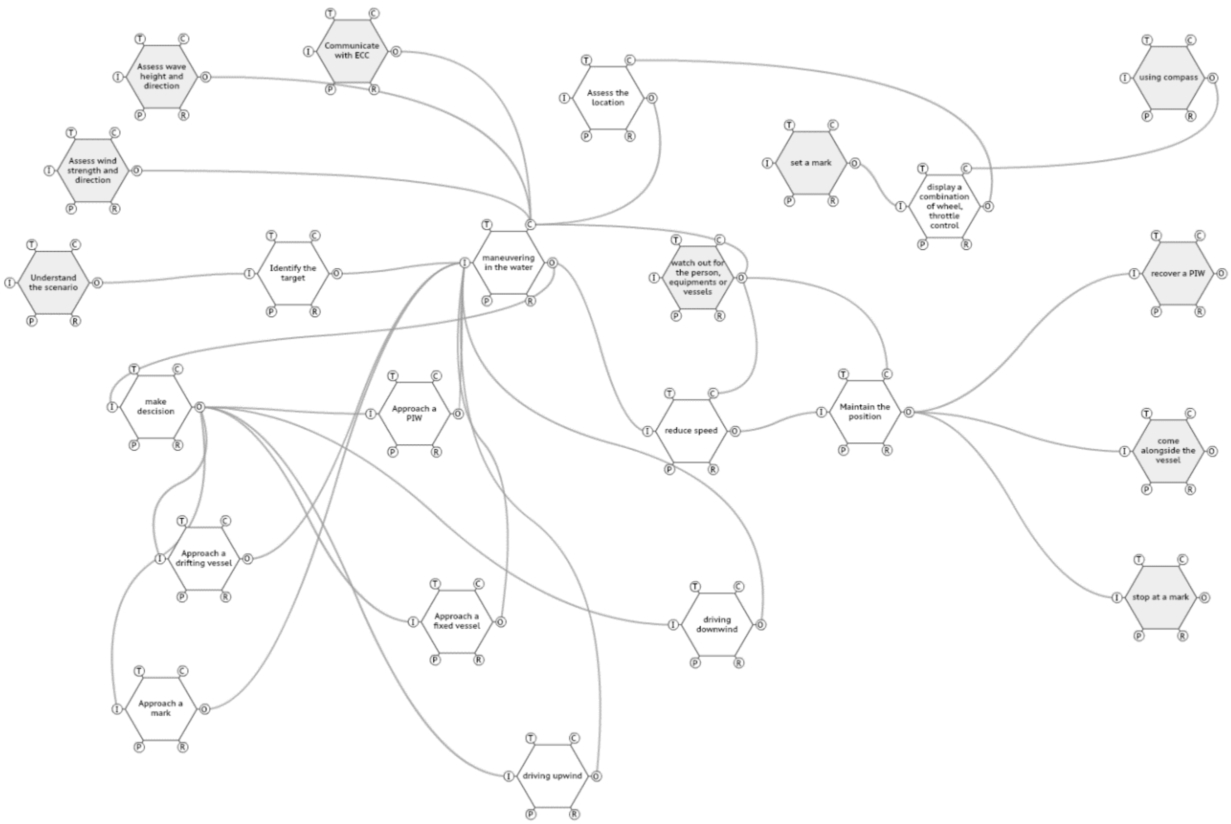


Figure 11. FRAM model of on-water tasks (Based on the training course material)

Although this model presents valuable information about the lifeboat operation, it doesn't cover all the system's important functions. Also, an operation in the lifeboat simulator will be done by individuals, and some teamwork activities, such as assigning responsibilities to the crew or identifying personnel for specialties, have not been simulated in the lifeboat simulator used for this study.

4.1.2 Scoring Rubric

Next FRAMs were built based on the grading rubrics (Figure 12 and Figure 13). This document consists of 3 parts: launching tasks, navigation tasks, and on-water tasks (Billard & Smith, 2018). FRAMs of launching tasks and on-water tasks were created separately, and navigation task functions were added to these two models. These models cover more functions of lifeboat operations than previous models (Figure 10 and Figure 11).

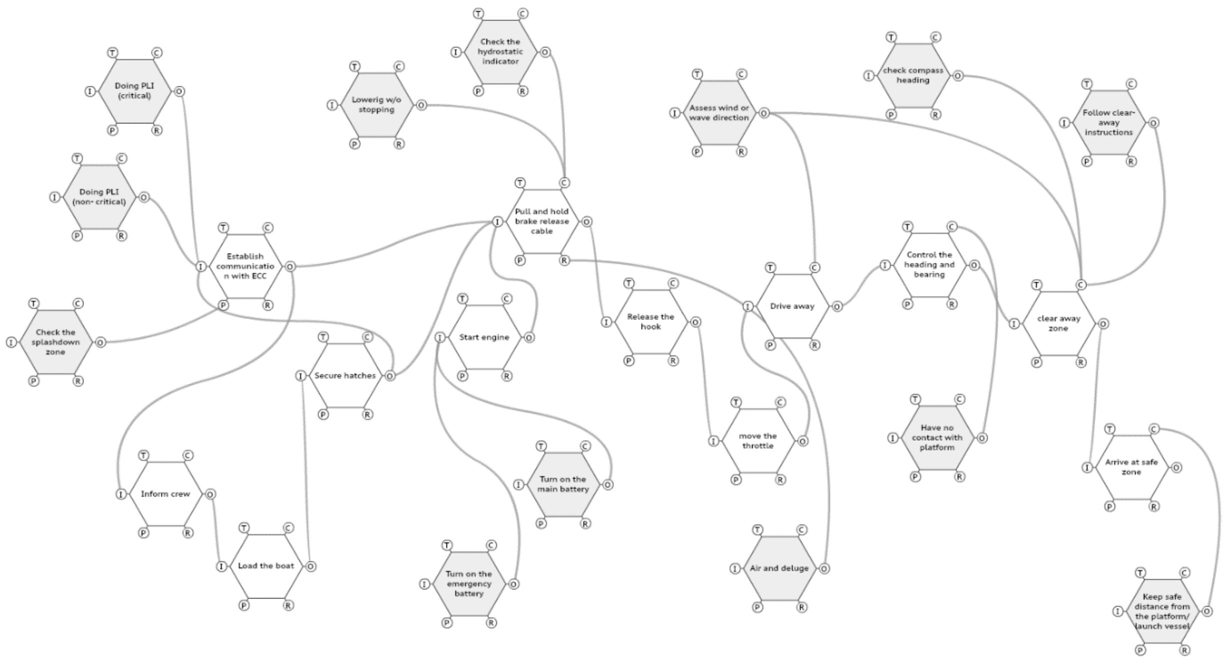


Figure 12. FRAM model of launching a lifeboat (Based on the scoring rubrics)

.

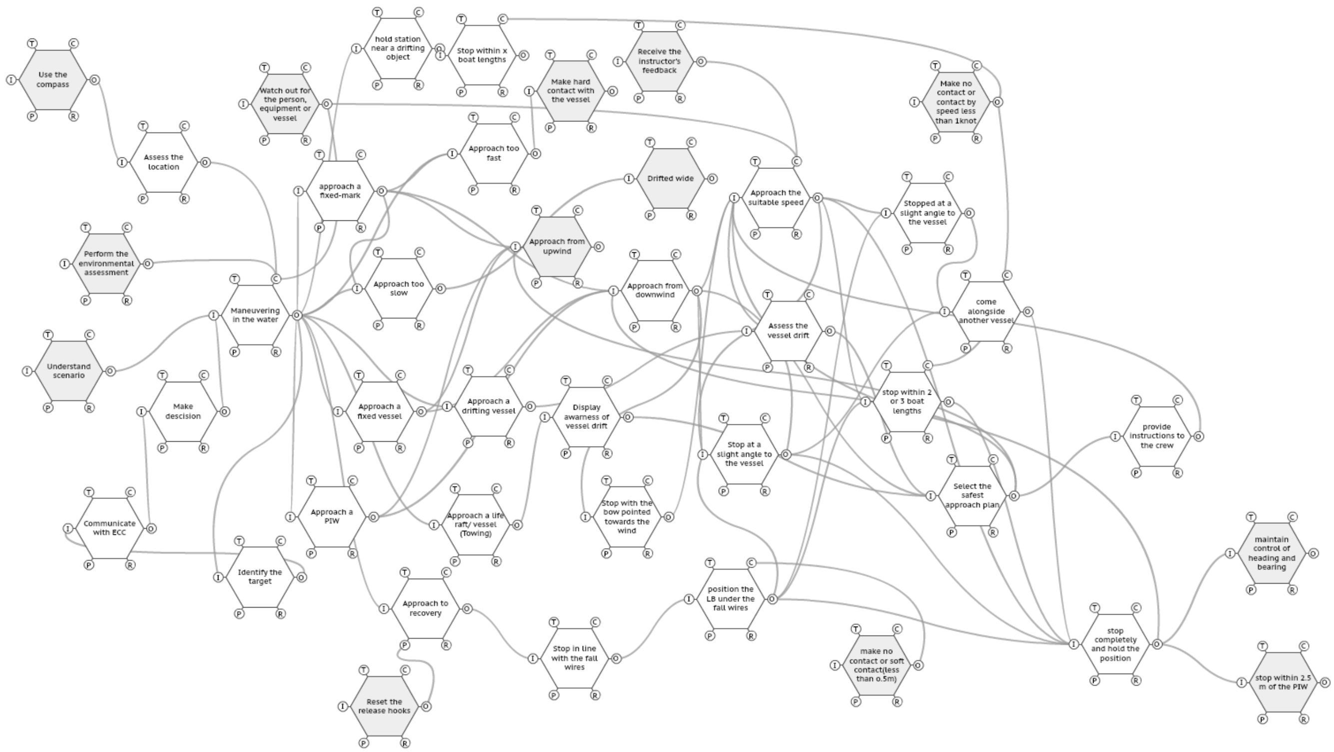


Figure 13. FRAM model of on-water tasks (Based on the scoring rubrics)

4.1.3 VM's lifeboat program scenarios

The FRAM is a way to visualize an operation to understand the functionality of a system. In this research, after creating FRAM models based on training course material and grading rubrics, it was decided to revise the FRAM models based on two principles: 1. Considering only two scenarios, and 2. Extracting functions that are measurable and trackable by the simulator. This was done because previous FRAM models consist of many functions, making it hard to track the trainee's performance. As a result, new FRAM models will have fewer functions than the last ones and be easier to understand scenarios. Also, using these models, the operation can be trackable in the simulator. Figure 14 and Figure 15 show the final FRAMs for launching and on-water tasks in the simulator. The sources for creating these models were documents of ACT course scenarios developed by VM and existing data files of past studies (Billard & Smith, 2018).

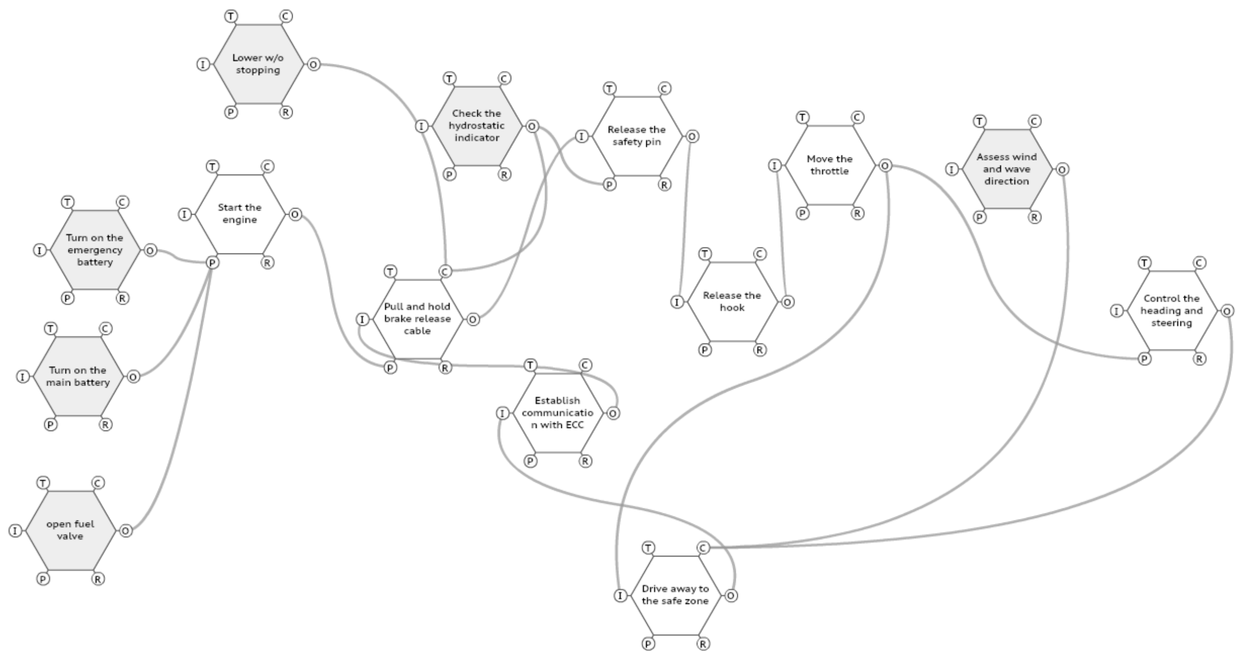


Figure 14. Revised FRAM model of launching a lifeboat

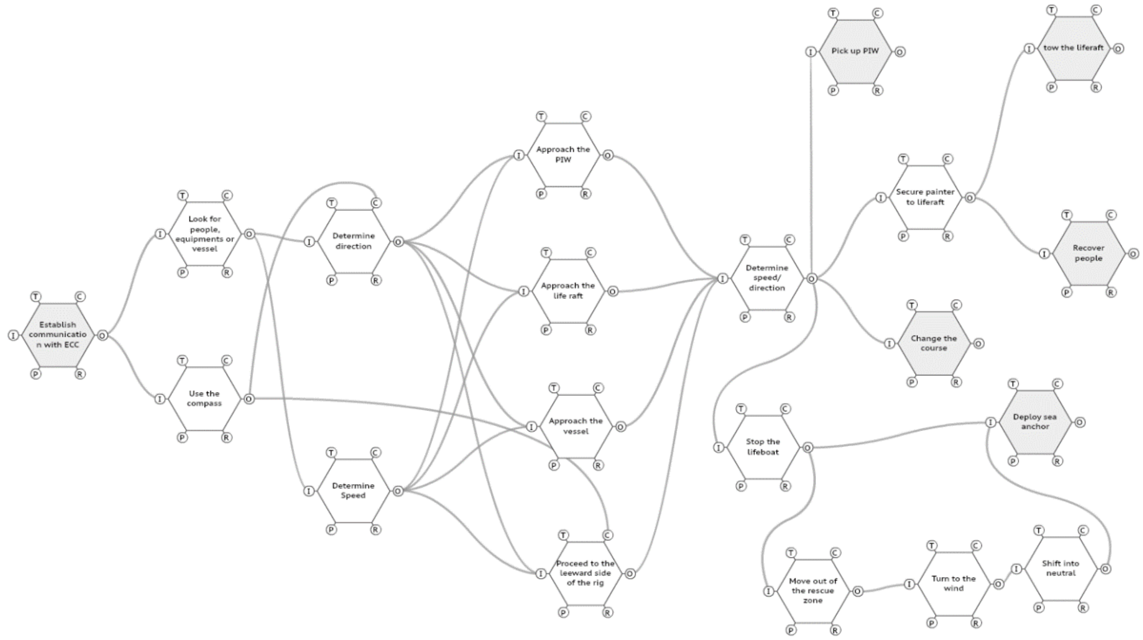


Figure 15. Revised FRAM model of on-water tasks

The FRAM models of launching the lifeboat and on-water tasks were combined to create one FRAM for the lifeboat operation (Figure 16). This FRAM was practiced with the simulator to evaluate the effectiveness of the model. The functional descriptions and the initial description of the aspects of lifeboat operations are provided in Appendix I.

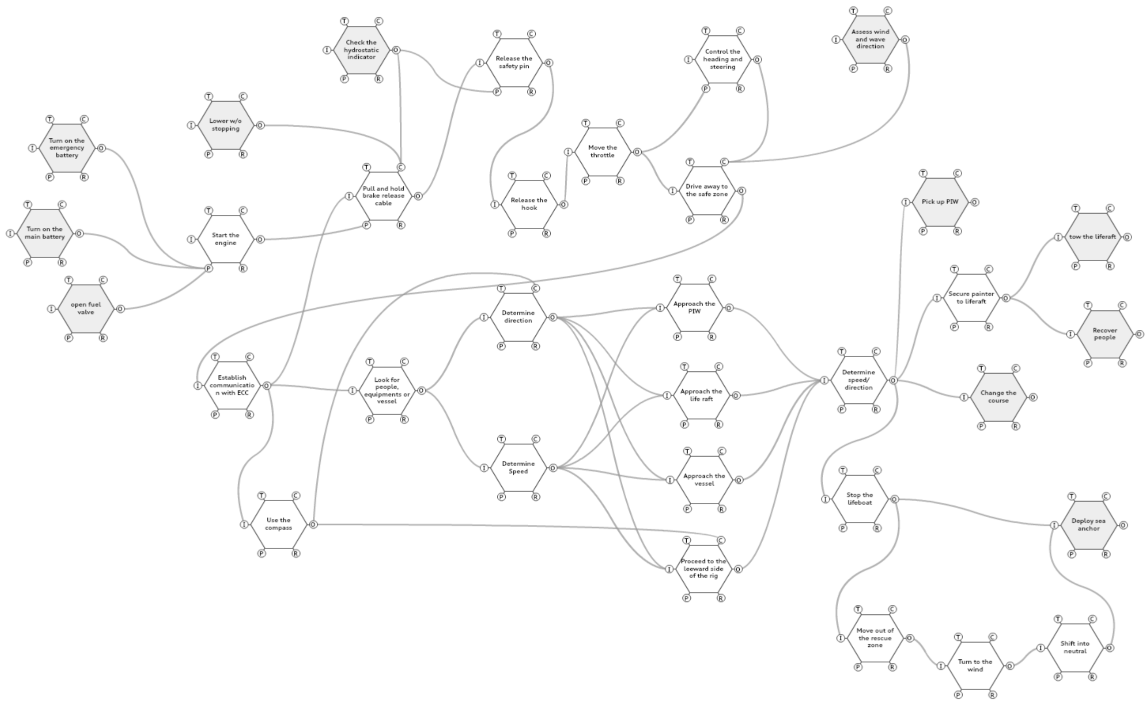


Figure 16. FRAM model of the lifeboat operation

4.2 Testing model and learning from variations

A map of potential ways a trainee can consider performing a scenario in the lifeboat simulator has been shown in Figure 16. However, there are many different actions that a trainee can do to finish a scenario, including the combination of the potential functions presented in Figure 16.

The FRAM model was tested by performing scenarios differently and using the FRAM model as a map to see if this model covers all necessary functions in these two scenarios. Table 7 andTable 8 show some sources of potential variabilities in terms of effective time and accuracy observed during the practice of launching a lifeboat and on-water tasks and possible consequences both in the real world and in the simulator for these activities. These variabilities have been extracted from the FRAM model and can be used to identify different outcomes of similar performance.

Table 7. Variability and possible consequences for launching a lifeboat

Launch a lifeboat		
Source of potential variability	Possible Consequence (Real world)	Consequence (Simulator)
Pulling the brake cable before receiving permission from ECC	• Casualty	• Fail the mission
Pulling the brake cable before starting the engine	• Casualty	• Fail the mission
Lowering the cable by having some stop in between	• Casualty	• Lose the point
Releasing the hook without checking the hydrostatic indicator. (Before entering the water completely)	• Releasing a boat at a considerable elevation from water can be dangerous and cause injury	• Lose the point • In case of collision, fail the mission

Trying to release the hook before releasing the safety pin	• The hook wouldn't be released before removing the safety pin. As a result, the trainee loses time at a critical moment, and a collision with the platform might happen.	• Lose the point • In case of collision, fail the mission
Moving the boat before releasing the hook	• Casualty	• Fail the mission
Starting to move with delay or not putting the throttle at the maximum speed	• The boat is in the hazard zone and has to be moved quickly. Any delay can be dangerous and cause casualty	• Lose the point • In case of collision, fail the mission
Lake of skill to control the heading and steering	• Cannot drive away from the platform and make a collision	• In case of collision, fail the mission
Making no assessment of the wind and current direction	• Cannot drive away from the platform and make a collision	• In case of collision, fail the mission

Table 8. Variability and possible consequences for on-water tasks

On-water tasks		
Source of potential variability	Possible Consequence (Real world)	Consequence (Simulator)
Driving fast in the area close to the object	• Not able to maintain the position to pick up a PIW or secure painter to the life raft. • Pass the object and lose it • Casualty	• May lose mark (in case of missing the object on the first try or having soft contact with the vessel or life raft) • Fail the mission (have contact with PIW or hard contact with the vessel or life raft)
Approaching the object from the wrong heading	• Not able to maintain the position to pick up a PIW or secure painter to the life raft. • Pass the object and lose it • Casualty	• May lose mark (in case of missing the object on the first try or having soft contact with the vessel or life raft) • Fail the mission (have contact with PIW or hard contact with the vessel or life raft)

Lack of skill in maneuvering the boat (control the heading and steering)	• Not able to maintain the position to pick up a PIW or secure painter to the life raft. • Pass the object and lose it • Casualty	• May lose mark (in case of miss the object in the first try or have soft contact with the vessel or life raft) • Fail the mission (have contact with PIW or hard contact with the vessel or life raft)
Driving fast when towing a life raft	• The painter may be released, and the lifeboat become disconnected	• In case of disconnecting, fail the mission

4.3 Dynamic FRAM modeling

A beneficial tool for teaching students can be identifying error patterns. Researchers attempted to identify a subset of events that showed either a solution technique or an error pattern (de Klerk et al., 2015b). To effectively understand success and failure, you need to model the system as comprehensively as possible, including the relationships between the systems. An appropriate metric should be used to track performance, taking the concept of success and failure from binary into a continuous high-to-low performance scale (Khan et al., 2018).

In this research, the FRAM has been used to understand the process that produces each result. The FRAM enables the visualization of complicated work processes and dynamic conditions (Smith et al., 2018). The FRAM explains the functionality of a system. A FRAM should be able to explain the success and failures of a system, which is important in understanding the system "comprehensively."

4.3.1 Successful and unsuccessful performance signatures

The model was tested once it was finalized (section 4.2). The goal of evaluating the FRAM model was to study trainees' performances in order to learn about the role of active functions in lifeboat operations and how to distinguish an acceptable performance from an unacceptable one. This section presents two performances (successful and unsuccessful) for each task, including launching a lifeboat, getting alongside a vessel, transferring a PIW, and picking up a PIW. The scoring rubrics developed by VM and the simulator's pass/fail system were used to consider a performance successful or unsuccessful.

4.3.1.1 Launch a lifeboat

Table 9 presents details about an unsuccessful performance, and Table 10 presents details about a successful performance for launching a lifeboat. As shown in Table 9 andTable 10, "…*each scenario included the number of active functions, the time required for execution of each active function, the output(s) of each active function, downstream coupled function, and coupled function aspects*"(Salehi, Hanson, et al., 2021). The final model and two scenarios were then imported into the DynaFRAM. The result of running DynaFRAM is a visual representation of how a trainee performed a task in the simulator. Figure 17 presents an example of an unsuccessful performance of launching a lifeboat, while Figure 18 presents a successful launch.

Table 9. Details of an unsuccessful performance of launching a lifeboat

Time	Active Function	Active Function Output	Downstream Coupled Function	Coupled Function Aspect
0	Establish communication with ECC	Permission yes	Pull and hold the brake release cable	I
2	Turn on the main battery	Ok	Start the Engine	P
5	Open fuel valve	Ok	Start the Engine	P
8	Start the Engine	Ok	Pull and hold the brake release cable	P
12	Lower w/o stopping	Smooth	Pull and hold the brake release cable	C
12	Check the hydrostatic indicator	No	Pull and hold the brake release cable	C
12	Pull and hold the brake release cable	Boat is not in the water	Release the safety pin	I
12	Release the safety pin	Safety pin is removed	Release the hook	I
30	Release the hook	Boat is free	Move the throttle	I
38	Move the throttle	Heading 280	Make collision	I

Table 10. Details of successful performance of launching a lifeboat

Time	Active Function	Active Function Output	Downstream Coupled Function	Coupled Function Aspect
0	Establish communication with ECC	Permission yes	Pull and hold the brake release cable	I
2	Turn on the main battery	Ok	Start the Engine	P

4	Open fuel valve	Ok	Start the Engine	P
7	Start the Engine	Ok	Pull and hold the brake release cable	P
10	Lower w/o stopping	Smooth	Pull and hold the brake release cable	C
10	Check the hydrostatic indicator	Color checked	Pull and hold the brake release cable	C
10	Check the hydrostatic indicator	Color checked	Release the safety pin	P
10	Pull and hold the brake release cable	Boat is in the water	Release the safety pin	I
24	Release the safety pin	Safety pin is removed	Release the hook	I
27	Release the hook	Boat is free	Move the throttle	I
30	Move the throttle	Heading 175	Drive away to the safe zone	I
33	Assess wind and wave direction	Ok	Drive away to the safe zone	C
33	Control the heading and steering	Ok	Drive away to the safe zone	C

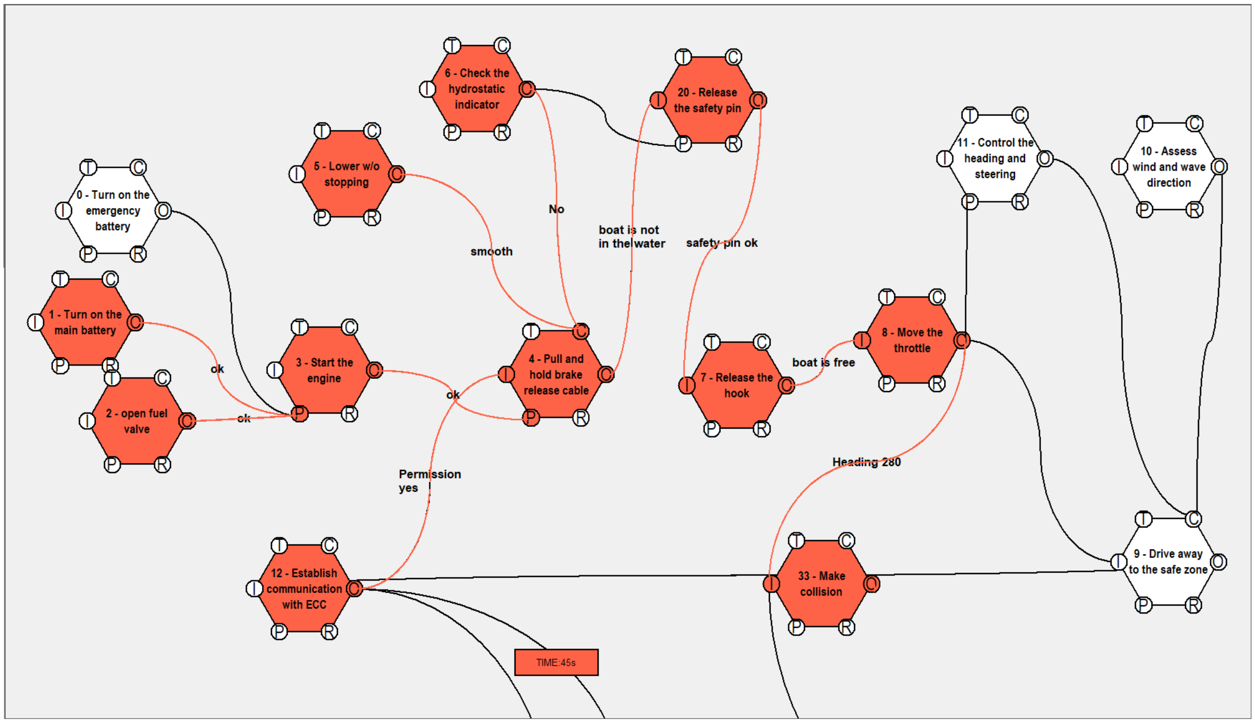


Figure 17. An example of an unsuccessful performance for launching a lifeboat

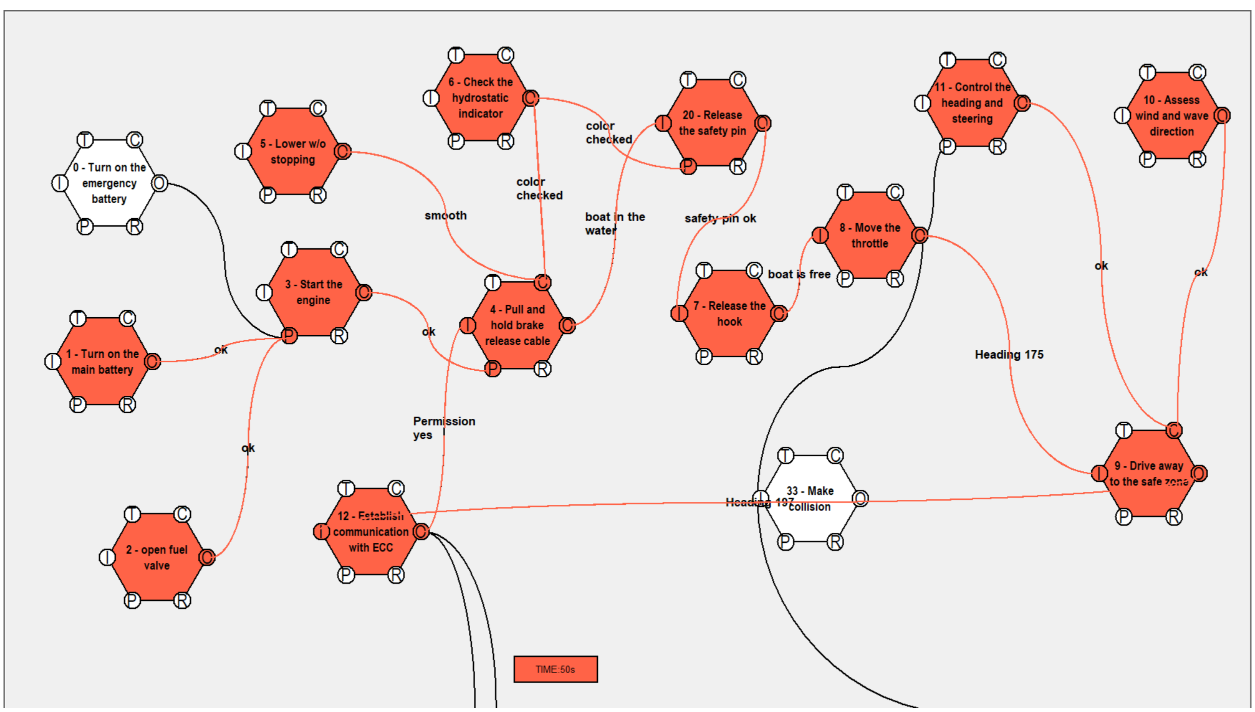


Figure 18. An example of successful performance of launching a lifeboat

From these signatures, it can be seen that paying attention to the hydrostatic indicator and releasing the safety pin at a proper time (when the boat is in the water), having the ability to control heading and steering, and assessing the wind and current directions to choose the best heading to get away from the hazard area and go to the safe zones are some key points to have a successful operation.

4.3.1.2 On-water tasks

In terms of on-water tasks, two objectives are analyzed in this section: 1. Stop by a vessel and transfer PIW in scenario 1, and pick up the PIW in scenario 2. Details and signatures of a successful and an unsuccessful operation will be presented.

- **Scenario 1 (Stop by a vessel and transfer PIW)**

In scenario one, after towing a life raft, trainees were asked to stop alongside a recovery vessel and transfer PIW. Details of an unsuccessful and successful performances are provided in Table 11 andTable 12.

Table 11. Details of an unsuccessful performance of stopping by a vessel and transferring PIW

Time	Active Function	Active Function Output	Downstream Coupled Function	Coupled Function Aspect
0	Establish communication with ECC	Look for the recovery vessel	Look for people, equipment, or vessel	I
4	Look for people, equipment, or vessel	Heading 50 to 65	Determine direction	I
4	Look for people, equipment, or vessel	Driving fast	Determine speed	I
10	Determine direction	Heading 40 to 103	Approach the vessel	I

10	Determine speed	Drive fast	Approach the vessel	I
16	Approach the vessel	Heading 57 reverse to bring the boat to stop	Determine speed/ direction	I
24	Determine speed/ direction	Pass the target	Change the course	I

Table 12. Details of successful performance of stopping by a vessel and transferring PIW

Time	Active Function	Active Function Output	Downstream Coupled Function	Coupled Function Aspect
0	Establish communication with ECC	Look for the recovery vessel	Look for people, equipment, or vessel	I
5	Look for people, equipment, or vessel	Heading 50 to 60	Determine direction	I
5	Look for people, equipment, or vessel	Driving fast	Determine speed	I
10	Determine direction	Heading 67	Approach the vessel	I
12	Determine speed	put the throttle in the neutral position	Approach the vessel	I
15	Approach the vessel	Reverse to bring the boat to stop, heading 80	Determine speed/ direction	I
20	Determine speed/ direction	put the throttle in the neutral position and maintain the position	Stop the lifeboat	I
25	Stop the lifeboat	Transfer the MOB and release the painter	Move out of the rescue zone	I

This data was used to create two signatures of an unsuccessful (Figure 19) and a successful performance (Figure 20).

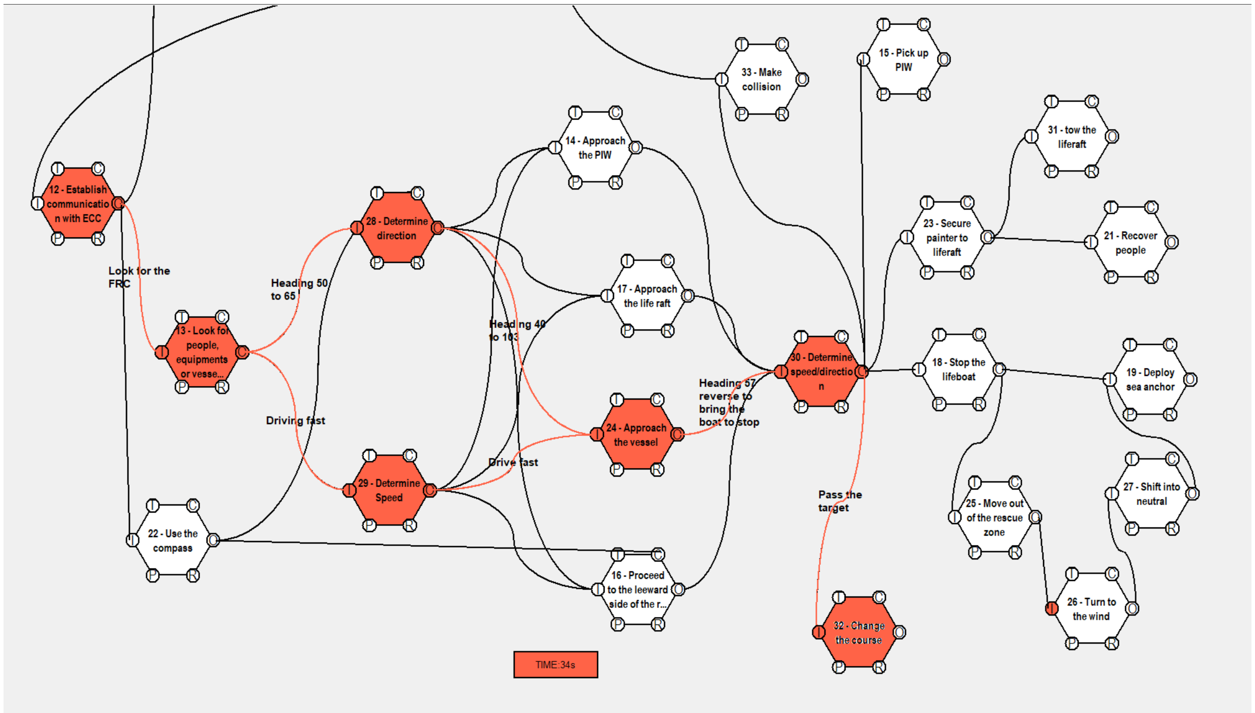


Figure 19. An example of an unsuccessful performance of stopping by a vessel and transferring PIW

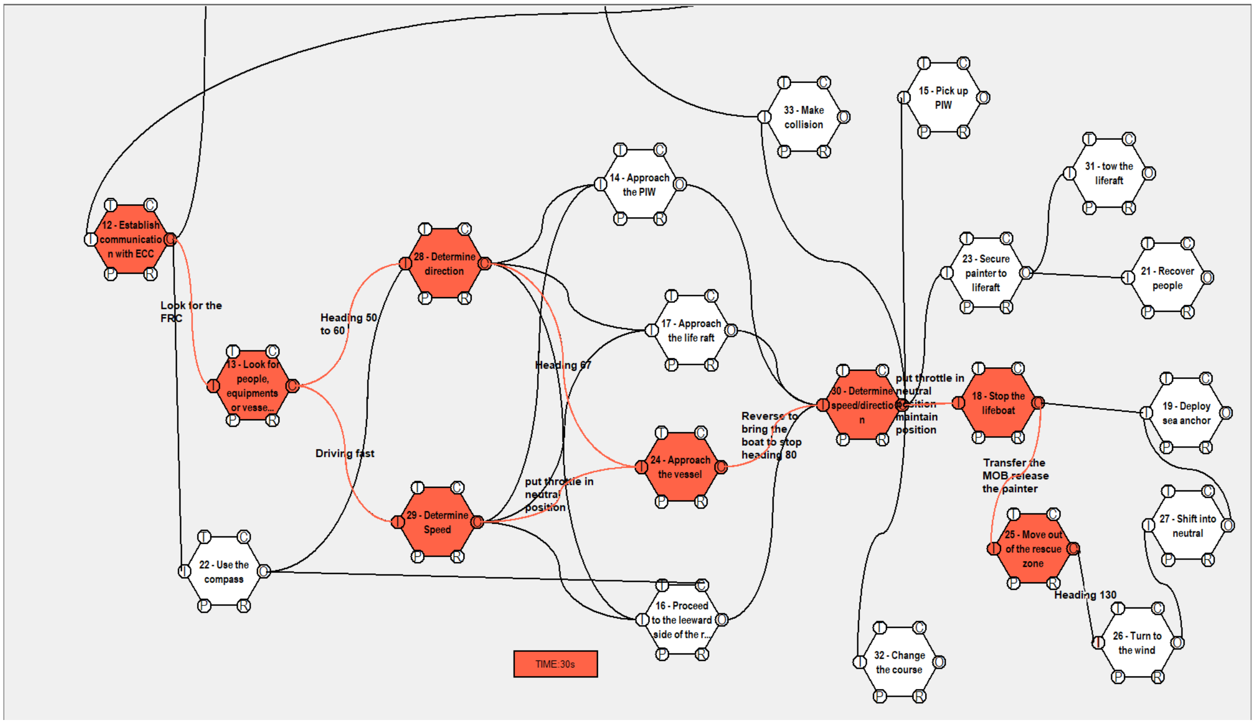


Figure 20. An example of successful performance of stopping by a vessel and transferring PIW

It can be seen from Figure 19 that the volunteer was not able to stop by the vessel on the first try. They needed to change the course and approach the vessel again. It seems that both volunteers followed a similar heading and tried to stop the boat when they were close to the vessel (Figure 19 and Figure 20). But what did make one operation successful and one unsuccessful? The answer can be found in their speed before approaching the vessel. The first volunteer drove fast before approaching the vessel (Figure 21). As a result, when he/she got close to the recovery vessel, though he/she reversed the throttle, the boat wasn't stopped, and it passed the starboard side safe zone of the recovery vessel. On the other hand, the other volunteer drove gradually and decreased the speed before getting close to the recovery vessel (Figure 21). In this case, when he/she was in the safe zone, the boat was stopped by reversing the throttle, and PIW was transferred to the recovery vessel.

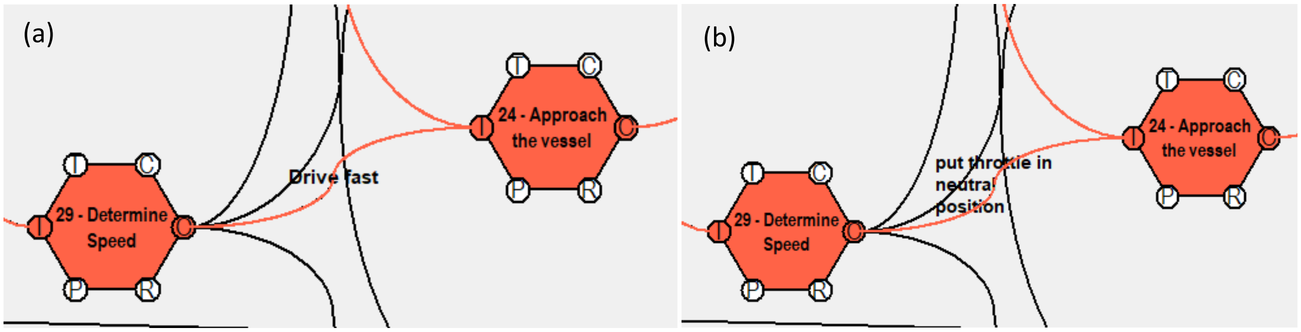


Figure 21. Difference between (a) unsuccessful and (b) successful performance

It was not the only function that could be effective in this operation. Other parameters, such as the trainee's skill to drive and control the boat, when he/she decided to stop the lifeboat, and the distance between the lifeboat and recovery vessel, can also be important.

- **Scenario 2 (Pick up a PIW)**

In the second scenario, after launching the lifeboat, the trainee must find 2 PIWs and pick them up. Table 13 shows details of an unsuccessful attempt to pick up a PIW on the first try, and Table 14 presents a successful performance.

Table 13. Details of the unsuccessful performance of picking up a PIW

Time	Active Function	Active Function Output	Downstream Coupled Function	Coupled Function Aspect
0	Establish communication with ECC	Search for a PIW, Heading 272	Look for people, equipment, or vessel	I
7	Look for people, equipment, or vessel	Heading 196	Determine direction	I

7	Look for people, equipment, or vessel	Drive gradually	Determine speed	I
11	Determine direction	Heading 259	Approach the PIW	I
11	Determine speed	Slow the boat	Approach the PIW	I
15	Approach the PIW	Heading 262, drive slowly	Determine speed/ direction	I
18	Determine speed/ direction	Unable to catch the PIW	Change the course	I
22	Change the course	Make a turn	Look for people, equipment, or vessel	I

Table 14. Details of the successful performance of picking up a PIW

Time	Active Function	Active Function Output	Downstream Coupled Function	Coupled Function Aspect
0	Establish communication with ECC	Search for a PIW, heading 183	Look for people, equipment, or vessel	I
10	Look for people, equipment, or vessel	Heading 155	Determine direction	I
15	Look for people, equipment, or vessel	Drive gradually	Determine speed	I
21	Determine direction	Heading 110	Approach the PIW	I
21	Determine speed	Reverse to bring the boat to stop	Approach the PIW	I
25	Approach the PIW	Heading 49, drive slowly	Determine speed/ direction	I

28	Determine speed/ direction	Heading 34, put the throttle in the neutral position	Pick up PIW	I
32	Pick up PIW	Pick up PIW1	Establish communication with ECC	I

An unsuccessful and successful performance for picking up a PIW are visualized in Figure 22 and Figure 23, respectively.

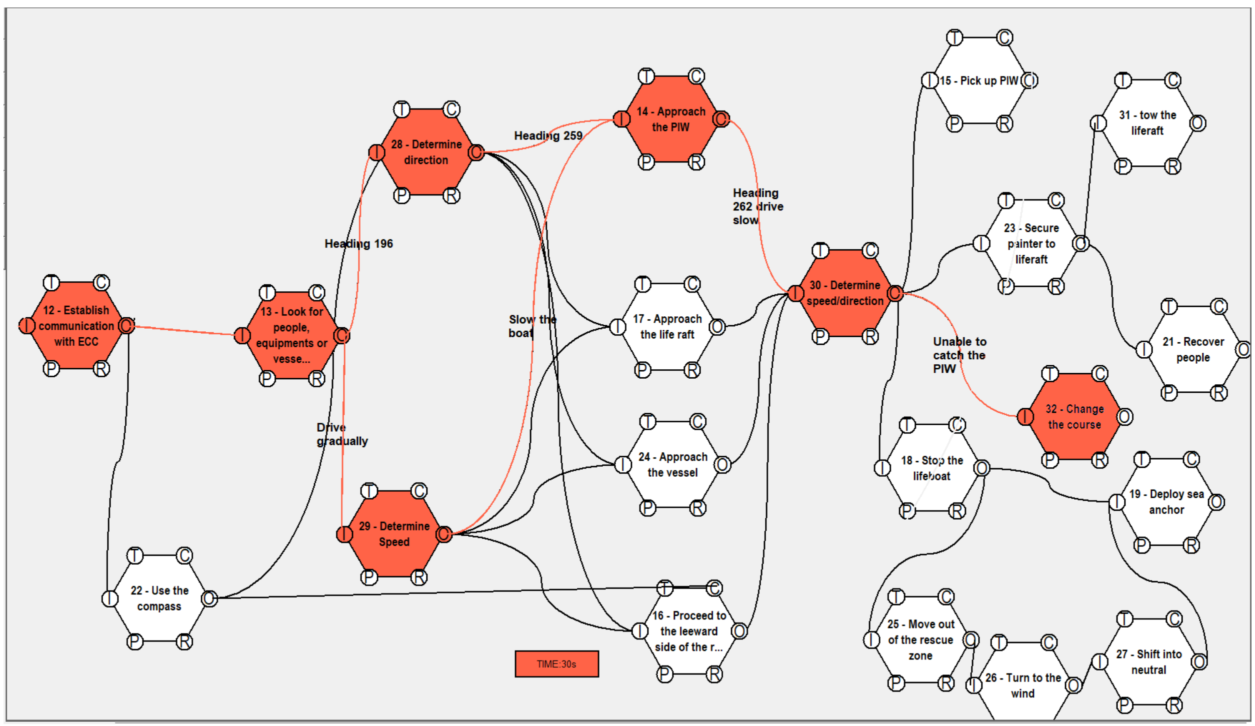


Figure 22. An example of an unsuccessful performance of picking up a PIW

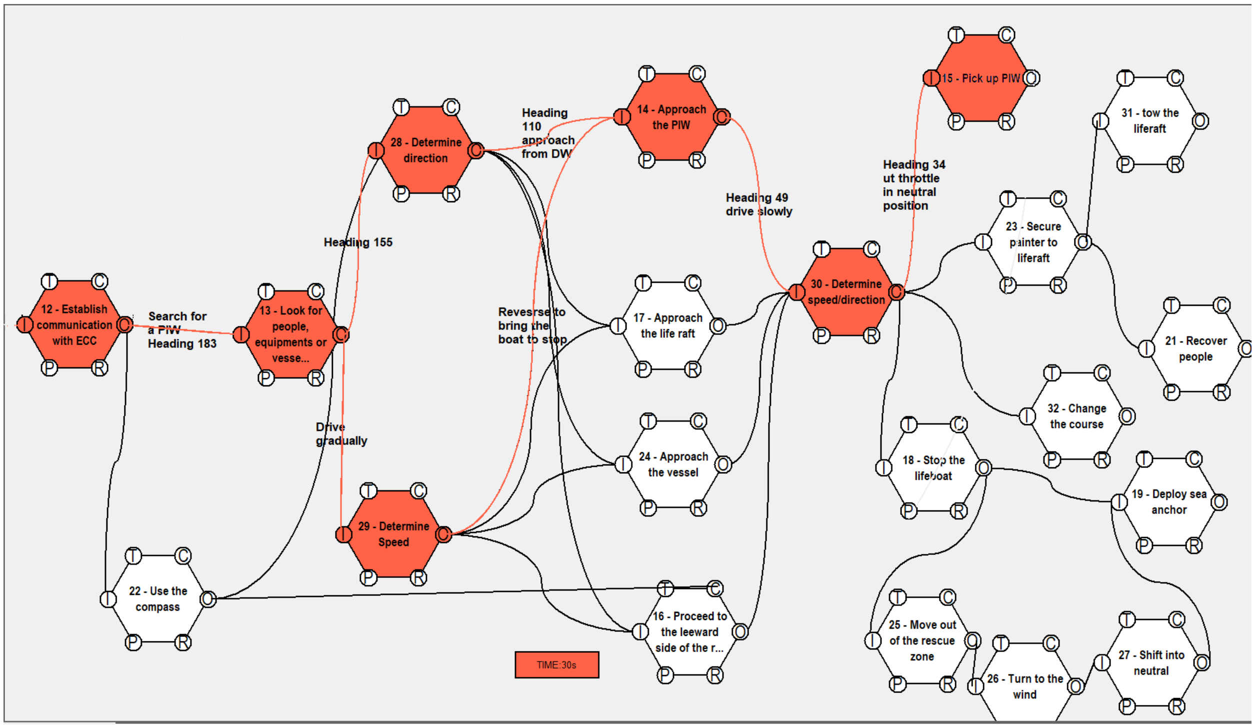


Figure 23. An example of successful performance of picking up a PIW

In this example, the more obvious difference between the two performances is choosing different headings to approach and pick up the PIW. The first volunteer tried to approach from the upwind direction, while the second volunteer tried from the downwind. If the weather was calm in this scenario, the first volunteer might have been able to catch the casualty but because of wind and current, approaching from upwind is risky with a low chance of success. As a result, assessing weather conditions is one function that can affect other functions' outcomes.

Some examples of successful and unsuccessful operations performed by volunteers are presented in this section. The FRAM model was used to identify essential functions of the system and highlight different variations between performances. This led to identifying important keys between acceptable and unacceptable performances (Section 5.3.1). Video files capturing signatures of successful and unsuccessful performances of launching the lifeboat and on-water tasks are provided in Appendix II.

5. Discussion and Recommendations

5.1 The capability of the FRAM for modeling the lifeboat operation

The FRAM was used in this study to represent and describe the process of launching and maneuvering a lifeboat with the simulator by coxswains. Billard et al. (2020) used the HPP to define how a trainee can successfully complete a task in a lifeboat scenario. This study implemented the FRAM to recognize and categorize the main functions of a lifeboat operation performed by trainees in the simulator. The FRAM model covers both launching and on-water tasks for a lifeboat. Visualizing the process and highlighting essential functions in a lifeboat operation by the FRAM resulted in identifying effective parameters leading to success or failure in achieving the goal by the trainee in the simulator. More examples of performance may help learn additional functionality to include in the FRAM.

5.2 Monitoring the lifeboat operation by the FRAM

The equivalency of success and failures is a key premise of the FRAM and resilience engineering. This indicates that both acceptable and unsatisfactory outcomes come off in a similar way (Hollnagel, 2012). Observing different performances during the lifeboat training course provided insight into diagnosing good performances vs. bad ones. The modified version of the FRAM findings revealed that successful and failed operations are founded on the same set of functions. Visualizing signatures led to identifying important functions in having a successful operation. Some volunteers had experience with the lifeboat simulator or the actual lifeboat and could finish the scenario successfully on the first try. However, when the details of their performances were checked by a lens of FRAM, it was found out that not all of their performance were done such as an expert, and to categorize their overall performance as an expert, they need to practice in some aspects.

On the contrary, it was the first time some volunteers had performed lifeboat operations with the simulator. FRAM signatures extracted from their performance show that although they failed to complete some operations successfully, they functioned as experts in some other ways.

The FRAM model was created to visualize a lifeboat operation and understand it thoroughly. In addition, it is possible to evaluate a trainee's performance and decisions based on this model.

5.2.1 Acceptable and non-acceptable performance

These signatures were examples of performances for some tasks with different outcomes in the lifeboat operation. The variabilities are not limited to factors observed in the mentioned examples. Any performance may lead to emerging a new variation. Identifying these functions and their variations is one way to discover when and how a trainee acted differently in the lifeboat operation. Some key points were extracted by monitoring performances in the lifeboat simulator. A comparison between acceptable and unacceptable performances for launching a lifeboat is presented in Table 15.

Table 15. Acceptable and unacceptable performance for launching a lifeboat

Unacceptable	Acceptable
Starting the launch without asking for permission	Waiting to receive permission from ECC before starting the launch

Pulling the brake release cable before starting the engine	Starting the engine before pulling the brake release cable
Having some stops while pulling the brake release cable	Pulling the brake release cable smoothly
Releasing the safety pin before the boat is in the water (not checking the hydrostatic indicator)	Checking the hydrostatic indicator while pulling the cable and releasing the safety pin when the indicator changes
Forgetting to release the safety pin before releasing the hook or doing it with a delay	Releasing the safety pin as soon as the boat is in the water
Forgetting to release the hook before moving the throttle or doing it with a delay	Releasing the hook as soon as he/she releases the safety pin
Moving the throttle and putting it in the middle speed, or moving the throttle with a delay	Moving the throttle and put it on the maximum as soon as the hook is released
Not able to control the boat and make collision with the platform	Controlling the heading and steering while getting away from the platform
Not checking the wind and wave direction and by choosing the wrong heading, making a collision with the platform	Assessing the wind and wave direction and deciding on the best heading for getting away from the platform

Table 16 presents acceptable and unacceptable performances for on-water tasks.

Table 16. Acceptable and unacceptable performance for on-water tasks

Unacceptable	Acceptable
Ignoring instructions from ECC	Paying attention to the communication with ECC and following the instructions
Driving fast	Driving gradually
Reducing the speed after getting close to the target	Reducing the speed before getting close to the target (estimating the proper time to decrease the speed)
Towing the life raft with the maximum speed or so slow	Towing the life raft gradually
Having the speed of more than 1 knot when the boat is in the location of "maintaining the position"	Having the minimum speed or zero knots when the lifeboat is in the "maintaining position"
Lack of skill in maneuvering the lifeboat	Ability to maneuver the lifeboat
Ignoring the direction of the wind and current for driving the lifeboat	Assessing the wind and current direction and choosing the heading for maneuvering based on it.
Approaching from upwind or beam wind	Approaching from downwind
Just focusing on the target and making a collision with other objects or PIW presented in the area	When approaching a target, pay attention to the surroundings and check if there is anything such as a platform or another PIW in the area close to the lifeboat

5.2.2 The comprehensive FRAM model

By watching different volunteer samples and comparing various behaviors and signatures leading to a successful or unsuccessful performance (section 4.3.1), it is concluded that the FRAM's functions can be categorized into four groups: Action, Assessment, Decision-making, and Skill (Figure 24).

Based on the sample performances, there were some functions that volunteers missed or did incorrectly for the first time, but for the second time, they did them correctly. So, it seems they just needed a reminder to do these functions when transferring from the theory to the practical test. These functions are labeled as "action functions."

In the lifeboat training scenario, there are some situations that a trainee needs to do some assessment of the current situation. Observation of volunteer performance and results showed that some do not have a good understanding of the required assessments or are not taking the assessments seriously. However, there is no significant indicator to see whether volunteers did the assessment correctly or not, but the outcome of these functions will impact the functions in the decision-making category. These functions are named "assessment functions."

The next group is "decision-making," which is an important category. Watching different signatures and comparing the various performance resulted in the outcome of this category having an important role in failing or succeeding in a mission. Generally, speed and heading are two essential factors in approaching an objective. Unsuitable speed or direction to approach leads to passing the target or making a collision with it. The skill of analyzing situations and decision-making makes the best route and speed to be chosen.

The last category is about marine and maneuvering skills. It can be said that these functions will surely be affected by the decision-making category; still, they can be powerful enough to change the outcomes. For example, some volunteers made mistakes in choosing the speed and heading, and they were close to hitting the PIW, but in the end, they could avoid the accident and were able to achieve the goal. The reason was their capability to drive and control the boat and stop it at the last second. On the contrary, some volunteers chose a good approach in the case of heading and speed but missed the objective in the last few seconds because of a lack of skill to maintain the position near the target.

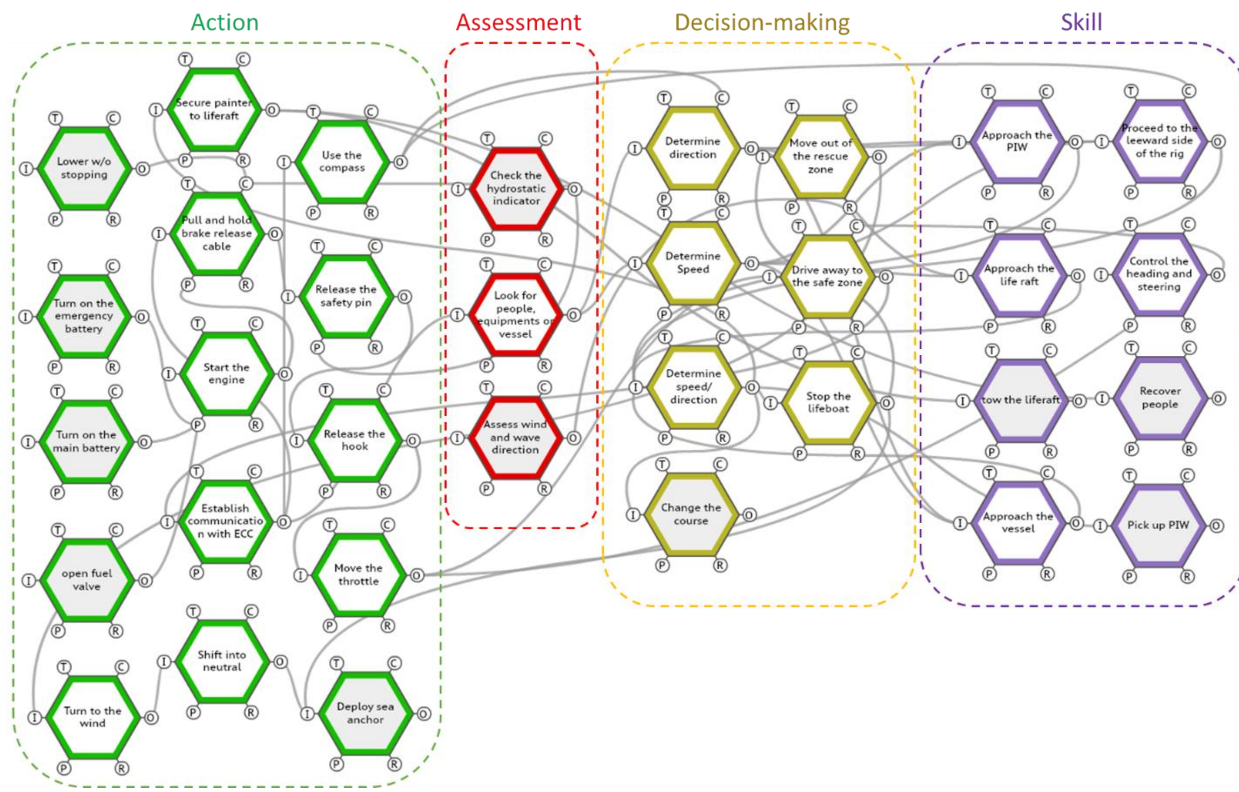


Figure 24. The comprehensive FRAM model of the lifeboat operation

It should be noted that this category is for a better understanding of different functions and their variations and doesn't mean that these functions need to be done in order of their category. For instance, an action function can be done before or after an assessment function. This model helps determine whether or not the coupling between functions and their potential variability can cause functional resonance in the lifeboat operation. The variability of an upstream function's output, which delivers the input, demand, resource, control, or time for a downstream function, may also contribute to the variability of a downstream function's output. Specification of upstream-downstream couplings is necessary to account for the accumulation of variability (Hollnagel, 2012). For example, the dependency between functions “check the hydrostatic indicator” and “pull and hold brake release cable” is an example of an upstream-downstream coupling. According to Figure 24, “check the hydrostatic indicator” as the upstream function controls the “pull and hold brake release cable” as the downstream function. 'This type of coupling is a fundamental basis of functional resonance (Salehi et al., 2021).

This model can be used to adapt the lifeboat training system to see which functions are significant in terms of their impact on other functions and outcomes, which functions need more practice, and which functions need more awareness rather than practice. A FRAM signature of a trainee’s performance can be used to determine whether they need to work on the maneuvering skill, assessment skill, or decision-making skill, or they need to have a checklist to remember the action functions. However, this model is based on a few trials and needs to be developed with more samples. By having different signatures, a better understanding of where in the scenario most failure happens and what functions cause failure, the training course can be developed to fix that problem.

5.3 Study limitations and future research

This qualitative FRAM-based study focused on just five volunteers during the testing phase of the FRAM modeling. Even though detailed information was acquired for each instance, the limited sample size of studied volunteers restricts the generalization of the study's outcomes. In addition, none of the volunteers acted completely like a novice or an expert, and there were overlaps in their performances. As a result, diagnosing an acceptable vs. unacceptable performance was challenging. For that purpose, subsequent studies will collect more data from trainees to broaden this study's scope. Future studies might focus on the variability of function output performance. This allows researchers to compute the aggregate of variability and offer appropriate strategies to manage variability in the lifeboat's regular tasks, improving the safety and quality of their performance. Meanwhile, increased variety and the number of novices or experts will strengthen the generalization of the findings.

Because of the existing data limitations, only a student FRAM model was created for this study. This model is beneficial in finding out what parameters are essential in a situation and why something just happened. The missing part of this model is where and when a trainee needs to receive feedback (Mislevy, 2011). Having an instructor model in hand can help answer this question and allow trainees to build their knowledge structure. It can be a separate FRAM model or a sublayer of the student FRAM model. Further research can be done by identifying the best feedback for a specific situation, the best time to receive feedback, and how feedback needs to be transferred to trainees. Furthermore, the possible gap between the trainee's model with an instructor's model will be a basis for improving the quality of training with the lifeboat simulator.

6. Conclusions

This research aimed to model virtual lifeboat training and analyze acceptable and unacceptable performance using FRAM. The functions to construct the FRAM were identified based on an approved training course, scoring rubrics, and two lifeboat scenarios developed by VM. The FRAM model consists of two parts: Launching and on-water tasks. Some potential sources of variability in terms of effective time and accuracy were determined for a lifeboat operation to identify the different outcomes of similar performances.

FRAM signatures of successful and unsuccessful performance explained how different functions of the system and their variabilities could affect other functions and the overall outcome. In launching, forgetting to ask permission for the launching, not releasing the safety pin, and lacking the skill to drive the boat to the safe zone were the most common mistakes among volunteer samples. In on-water tasks, driving at excessive speed, the incorrect direction to approach, lack of skill in maneuvering the boat, and making a collision with the platform while trying to pick up a PIW were major reasons for failing the mission. However, regarding the comprehensive FRAM model, incorrect assessment of the wind and direction can lead to making the wrong decision for heading and speed. Based on these results, the trainer can promote practices that lead to high performance and remove practices associated with poor performance.

As was mentioned before, the functions were classified into four categories: action, assessment, decision-making, and skill. The figure indicated that three functions are in the assessment group, which can affect the outcomes of functions in decision-making and action groups. In addition, eight functions are in the skill category mainly impacted by the functions of the decision-making group; still, in some conditions, they are effective enough to change the outcome.

Evaluating performances was done based on the rubrics scoring. However, the FRAM model showed that some functions need more attention in the evaluating system, such as checking the hydrostatic indicator and releasing the safety pin in time in launching and communicating with ECC, wind, and wave assessments in on-water tasks. As was mentioned before, some task variability might not be large enough to cause failure in the system, but the aggregation of these weak variabilities can intensify other functional variability and change the entire system's outcomes.

It is recommended to present this FRAM model to trainees as a guideline in the training program. Viewing this model, trainees can understand the scenario and required functions to achieve the goal. Also, it is suggested that instructors use the comprehensive FRAM model to identify the strengths and weaknesses of trainees during their performance and work on the parts that need more effort from them. Another suggestion is to use the FRAM model in an adaptive training system. Functional signatures of trainee's performance resulted in a better understanding of where in the scenario most failure happens, what functions cause failure, which functions need more practice, and how the training course can be developed to fix these problems.

References

Alamo, J., & Ross, M. (2017). Solve operator training in a challenging refining industry. *Hydrocarbon Processing*, *96*, 67–69.

Babicz, G. (2003). Simulation: Making it real. *Quality*, *42*(4), 90.

Bailey, J. H., & Witmer, B. G. (1994). Learning and transfer of spatial knowledge in a virtual environment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *38*(18), 1158–1162.

Bell, B. S., Kanar, A. M., & Kozlowski, S. W. J. (2008). Current issues and future directions in simulation-based training in North America. *The International Journal of Human Resource Management*, *19*(8), 1416–1434. https://doi.org/10.1080/09585190802200173

Billard, R., Musharraf, M., Veitch, B., & Smith, J. (2020). Using Bayesian methods and simulator data to model lifeboat coxswain performance. *WMU Journal of Maritime Affairs*, *19*, 295–312.

Billard, R., & Smith, J. J. E. (2018). Using simulation to assess performance in emergency lifeboat launches. *Proceedings, e Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC). Paper*, *19179*.

Billard, R., Smith, J., & Veitch, B. (2020a). Assessing lifeboat coxswain training Alternatives using a simulator. *The Journal of Navigation*, *73*(2), 455–470.

Billard, R., Smith, J., & Veitch, B. (2020b). Assessing lifeboat coxswain training Alternatives using a simulator. *The Journal of Navigation*, *73*(2), 455–470.

Billard, R., Smith, J., & Veitch, B. (2021). 2.0 CHAPTER 2: ASSESSING LIFEBOAT COXSWAIN TRAINING ALTERNATIVES USING A SIMULATOR. *ASSESSING AND PREDICTING HUMAN PERFORMANCE USING SIMULATOR DATA AND PROBABILISTIC METHODS*, 23.

Biswas, R., Veitch, B., & Power, S. D. (2020). Investigation of an EEG-based indicator of skill acquisition as novice participants practice a lifeboat maneuvering task in a simulator. *International Journal of Human–Computer Interaction*, *36*(8), 777–787.

Cabral, M. C., Morimoto, C. H., & Zuffo, M. K. (2005). On the usability of gesture interfaces in virtual reality environments. *Proceedings of the 2005 Latin American Conference on Human-Computer Interaction*, 100–108.

Darken, R. P. (2009). Identifying the limits of training system effectiveness through taxonomies of human performance. *Theoretical Issues in Ergonomics Science*, *10*(3), 231–243. https://doi.org/10.1080/14639220802151625

de Klerk, S., Veldkamp, B. P., & Eggen, T. J. H. M. (2015a). Psychometric analysis of the performance data of simulation-based assessment: A systematic review and a Bayesian network example. *Computers & Education*, *85*, 23–34.

de Klerk, S., Veldkamp, B. P., & Eggen, T. J. H. M. (2015b). Psychometric analysis of the performance data of simulation-based assessment: A systematic review and a Bayesian network example. *Computers & Education*, *85*, 23–34.

Dey, A., Chatburn, A., & Billinghurst, M. (2019). Exploration of an EEG-Based Cognitively Adaptive Training System in Virtual Reality. *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 220–226. https://doi.org/10.1109/VR.2019.8797840

Emad, G., & Roth, W. M. (2008). Contradictions in the practices of training for and assessment of competency: A case study from the maritime domain. *Education+ Training*.

Ernstsen, J., & Nazir, S. (2018). *Human error in pilotage operations*.

Ernstsen, J., & Nazir, S. (2020). Performance assessment in full-scale simulators – A case of maritime pilotage operations. *Safety Science*, *129*, 104775. https://doi.org/10.1016/j.ssci.2020.104775

Gerlach, I., Brüning, S., Gustavsson, R., Mandenius, C.-F., & Hass, V. C. (2014). Operator training in recombinant protein production using a structured simulator model. *Journal of Biotechnology*, *177*, 53–59.

Graf, S. (2014). Adaptive technologies. In *Handbook of research on educational communications and technology* (pp. 771–779). Springer.

Håvold, J. I., Nistad, S., Skiri, A., & Ødegård, A. (2015). The human factor and simulator training for offshore anchor handling operators. *Safety Science*, *75*, 136–145. https://doi.org/10.1016/j.ssci.2015.02.001

Hill, R., & Hollnagel, E. (2016). Instructions for use of the FRAM Model Visuliser (FMV). *Advances in Human Aspects of Transportation, Springer*, 399–411.

Hollnagel, E. (2012). *FRAM: The functional resonance analysis method: Modelling complex socio-technical systems, FRAM: The Functional Resonance Analysis Method: Modelling Complex Socio-technical Systems*. Ashgate Publishing. https://doi. org/10.1017/CBO9781107415324.

Hollnagel, E. (2018). *Safety–I and safety–II: the past and future of safety management*. CRC press.

Hollnagel, E., Wears, R. L., & Braithwaite, J. (2015). From Safety-I to Safety-II: a white paper. *The Resilient Health Care Net: Published Simultaneously by the University of Southern Denmark, University of Florida, USA, and Macquarie University, Australia*.

Kelley, C. R. (1969). What is adaptive training? *Human Factors*, *11*(6), 547–556.

Khan, F., Taylor, R., Veitch, B., Veitch, E., & Smith, D. (2018). Visualizing and understanding the operational dynamics of a shipping operation. *SNAME Maritime Convention*.

Kinateder, M., Ronchi, E., Nilsson, D., Kobes, M., Müller, M., Pauli, P., & Mühlberger, A. (2014). Virtual reality for fire evacuation research. *2014 Federated Conference on Computer Science and Information Systems*, 313–321.

Klein, G. (2008). Naturalistic decision making. *Human Factors*, *50*(3), 456–460.

Kluge, A., Nazir, S., & Manca, D. (2014). Advanced Applications in Process Control and Training Needs of Field and Control Room Operators. *IIE Transactions on Occupational Ergonomics and Human Factors*, *2*(3–4), 121–136. https://doi.org/10.1080/21577323.2014.920437

Kluge, A., Sauer, J., Schüler, K., & Burkolter, D. (2009). Designing training for process control simulators: A review of empirical findings and current practices. *Theoretical Issues in Ergonomics Science*, *10*(6), 489–509. https://doi.org/10.1080/14639220902982192

Kobes, M., Helsloot, I., de Vries, B., & Post, J. (2010). Exit choice,(pre-) movement time and (pre-) evacuation behaviour in hotel fire evacuation—Behavioural analysis and validation of the use of serious gaming in experimental research. *Procedia Engineering*, *3*, 37–51.

Landsberg, C. R., Astwood, R. S., Van Buskirk, W. L., Townsend, L. N., Steinhauser, N. B., & Mercado, A. D. (2012). Review of Adaptive Training System Techniques. *Military Psychology*, *24*(2), 96–113. https://doi.org/10.1080/08995605.2012.672903

Landsberg, C. R., Van Buskirk, W. L., Astwood Jr, R. S., Mercado, A. D., & Aakre, A. J. (2010). *Adaptive training considerations for use in simulation-based systems*. NAVAL AIR WARFARE CENTER TRAINING SYSTEMS DIV ORLANDO FL.

Magee, L. E. (2012). *Training effectiveness of the victoria class virtual submarine: A behavioural assessment of learning a complex task within a virtual environment*. Defence Research and Development Canada.

Malakis, S., & Kontogiannis, T. (2012). Refresher Training for Air Traffic Controllers: Is It Adequate to Meet the Challenges of Emergencies and Abnormal Situations? *The International Journal of Aviation Psychology*, *22*(1), 59–77. https://doi.org/10.1080/10508414.2012.635127

Manca, D., Nazir, S., Colombo, S., & Kluge, A. (2014). Procedure for automated assessment of industrial operators. *Chemical Engineering Transactions*, *36*, 391–396.

Manca, D., Nazir, S., Lucernoni, F., & Colombo, S. (2012). Performance Indicators for the Assessment of Industrial Operators. In I. D. L. Bogle & M. Fairweather (Eds.), *22nd European Symposium* *on Computer Aided Process Engineering* (Vol. 30, pp. 1422–1426). Elsevier. https://doi.org/10.1016/B978-0-444-59520-1.50143-3

Mania, K., Adelstein, B. D., Ellis, S. R., & Hill, M. I. (2004). Perceptual sensitivity to head tracking latency in virtual environments with varying degrees of scene complexity. *Proceedings of the 1st Symposium on Applied Perception in Graphics and Visualization*, 39–47.

Marcano, L., Haugen, F. A., Sannerud, R., & Komulainen, T. (2019). Review of simulator training practices for industrial operators: How can individual simulator training be enabled? *Safety Science*, *115*, 414–424. https://doi.org/10.1016/j.ssci.2019.02.019

McClernon, C. K., McCauley, M. E., O'Connor, P. E., & Warm, J. S. (2011). Stress training improves performance during a stressful flight. *Human Factors*, *53*(3), 207–218.

McMahan, R. P., Bowman, D. A., Zielinski, D. J., & Brady, R. B. (2012). Evaluating display fidelity and interaction fidelity in a virtual reality game. *IEEE Transactions on Visualization and Computer Graphics*, *18*(4), 626–633.

Millán, E., & Pérez-De-La-Cruz, J. L. (2002). A Bayesian diagnostic algorithm for student modeling and its evaluation. *User Modeling and User-Adapted Interaction*, *12*(2), 281–330.

Mislevy, R. J. (2011). Evidence-Centered Design for Simulation-Based Assessment. CRESST Report 800. *National Center for Research on Evaluation, Standards, and Student Testing (CRESST)*.

Morild Interaktive. (2017). *Morild Lifeboat—Full mission lifeboat simulator*. Morild Lifeboat - Full Mission Lifeboat Simulator. https://www.morildinteraktiv.no/morild-lifeboat#:~:text=The%20Morild%20Lifeboat%20simulator%20is,and%20recovery%20in%20scenario%20training.

Park, O., & Lee, J. (2013). Adaptive instructional systems. In *Handbook of research on educational communications and technology* (pp. 647–680). Routledge.

Patle, D. S., Ahmad, Z., & Rangaiah, G. P. (2014). Operator training simulators in the chemical industry: Review, issues, and future directions. *Reviews in Chemical Engineering*, *30*(2), 199–216. https://doi.org/doi:10.1515/revce-2013-0027

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International Encyclopedia of Education*, *2*, 6452–6457.

Ragan, E. D., Bowman, D. A., Kopper, R., Stinson, C., Scerbo, S., & McMahan, R. P. (2015). Effects of field of view and visual complexity on virtual reality training effectiveness for a visual scanning task. *IEEE Transactions on Visualization and Computer Graphics*, *21*(7), 794–807.

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Human Factors*, *45*(2), 218–233.

Salas, E., & Cannon-Bowers, J. A. (2001). THE SCIENCE OF TRAINING: A Decade. *Annu. Rev. Psychol*, *52*, 471–499.

Salas, E., Tannenbaum, S. I., Kraiger, K., & Smith-Jentsch, K. A. (2012). The Science of Training and Development in Organizations: What Matters in Practice. *Psychological Science in the Public Interest*, *13*(2), 74–101. https://doi.org/10.1177/1529100612436661

Salas, E., Wilson, K. A., Priest, H. A., & Guthrie, J. W. (2006). *Design, delivery, and evaluation of training systems.*

Salehi, V., Hanson, N., Smith, D., McCloskey, R., Jarrett, P., & Veitch, B. (2021). Modeling and analyzing hospital to home transition processes of frail older adults using the functional resonance analysis method (FRAM). *Applied Ergonomics*, *93*, 103392.

Salehi, V., Smith, D., Veitch, B., & Hanson, N. (2021). A dynamic version of the FRAM for capturing variability in complex operations. *MethodsX*, *8*, 101333.

Salehi, V., Veitch, B., & Smith, D. (2021). Modeling complex socio-technical systems using the FRAM: A literature review. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *31*(1), 118–142.

Smith, D., Veitch, B., Khan, F., & Taylor, R. (2018). Using the FRAM to understand Arctic ship navigation: Assessing work processes during the Exxon Valdez grounding. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, *12*(3).

Smith, D., Veitch, B., Khan, F., & Taylor, R. (2020). Integration of resilience and FRAM for safety management. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, *6*(2), 04020008.

Spetalen, H., & Sannerud, R. (2015). *Experiences with the use of simulation as transfer strategy*.

STCW, I. (2011). International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,(STCW) 1978, as amended in 1995/2010. *International Maritime Organisation, London, UK*.

Stevens, J. A., & Kincaid, J. P. (2015). The relationship between presence and performance in virtual simulation training. *Open Journal of Modelling and Simulation*, *3*(02), 41.

Stewart, J. E., Johnson, D. M., & Howse, W. R. (2008). *Fidelity requirements for Army aviation training devices: Issues and answers*. ARMY RESEARCH INST FOR THE BEHAVIORAL AND SOCIAL SCIENCES FORT RUCKER AL.

Tennyson, R. D., & Rothen, W. (1977). Pretask and on-task adaptive design strategies for selecting number of instances in concept acquisition. *Journal of Educational Psychology*, *69*(5), 586.

Van Merriënboer, J. J. G., Clark, R. E., & De Croock, M. (2002). Blueprints for complex learning: The 4C/ID-model. *Educational Technology Research and Development*, *50*(2), 39–61.

Van Rossum, J. H. A. (1990). Schmidt's schema theory: The empirical base of the variability of practice hypothesis: A critical analysis. *Human Movement Science*, *9*(3–5), 387–435.

Veitch, B., Billard, R., & Patterson, A. (2008). Evacuation Training Using Immersive Simulators. In *The Eighteenth International Offshore and Polar Engineering Conference*.

Velez, G., Matey, L., Amundarain, A., Suescun, Á., Marín, J. A., & de Dios, C. (2013). Modeling of Shotcrete Application for Use in a Real-Time Training Simulator. *Computer-Aided Civil and Infrastructure Engineering*, *28*(6), 465–480.

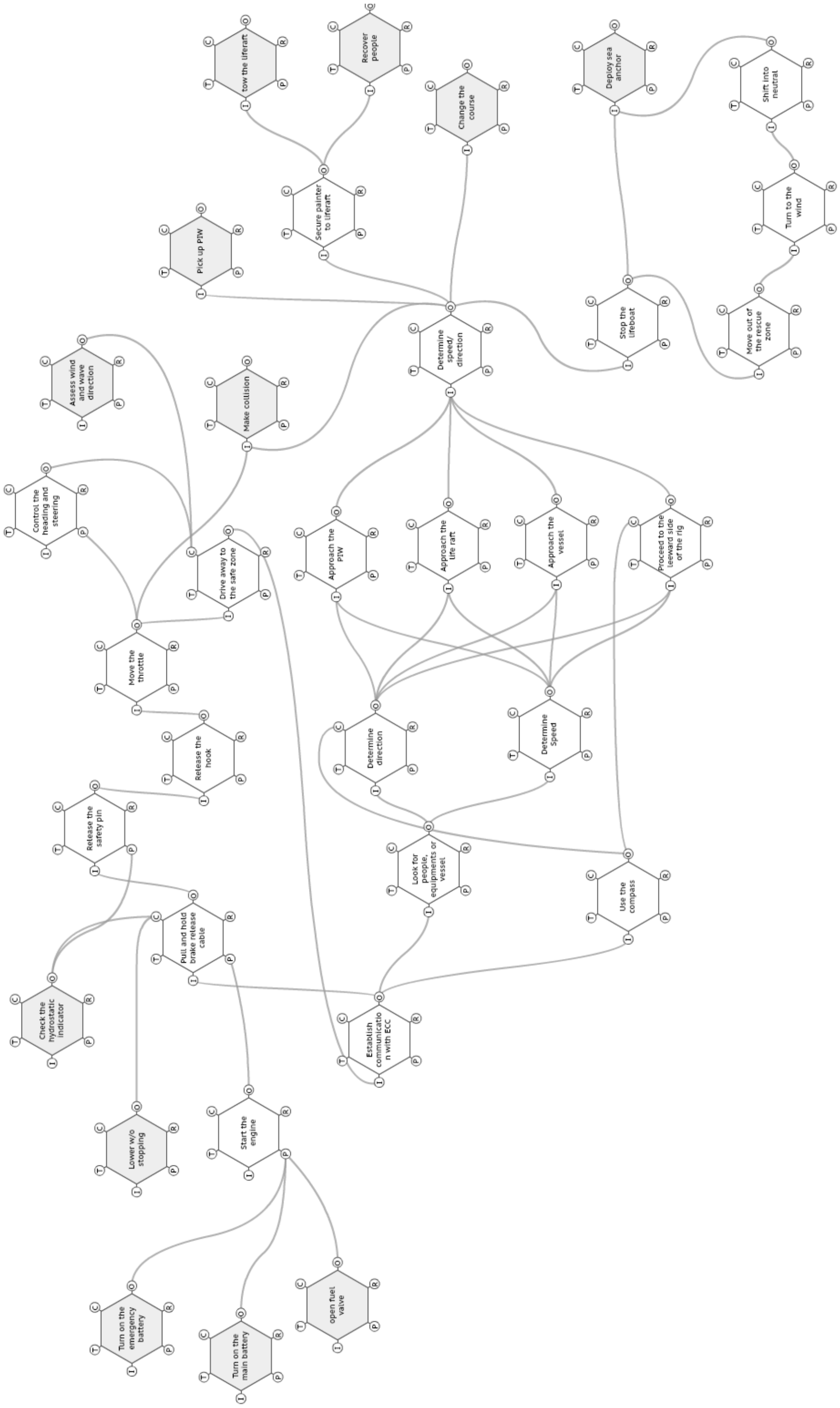
Virtual Marine. (2022). *Virtual Marine Lifeboat Simulators*. Lifeboat Simulators. https://www.virtualmarine.ca/our-products

Williams-Bell, F. M., Kapralos, B., Hogue, A., Murphy, B. M., & Weckman, E. J. (2015). Using serious games and virtual simulation for training in the fire service: A review. *Fire Technology*, *51*(3), 553–584.

Appendices

Appendix I

FRAM model of the lifeboat operation



Functional descriptions and the initial description of the aspects of lifeboat operations

Name of function	Establish communication with ECC
Description	Talk to ECC to get permission for launching, in addition, to reporting the situation and getting orders or information about different missions
Aspect	Description of Aspect
Input	Contacted ECC
Output	Permission issued Mission issued Information about the mission was transmitted

Name of function	Start the engine
Description	The engine needs to be started before launching.
Aspect	Description of Aspect
Input	
Output	Engine is turned on
Precondition	Electricity Injected Fuel injected to the engine

Name of function	Open the fuel valve
Description	To start the engine, the fuel valve should be open
Aspect	Description of Aspect
Output	Fuel is injected into the engine

Name of function	Turn on the battery
Description	The main or emergency battery must be used to start the engine.
Aspect	Description of Aspect
Output	Electricity Injected

Name of function	Pull and hold brake release cable
Description	Launching will start by pulling the brake release cable. If it starts before getting permission from ECC, the mission will be failed.
Aspect	Description of Aspect
Input	permission issued
Output	The lifeboat is in the water
Precondition	Engine is turned on
Control	Pull the cable without stopping Check the indicator color

Name of function	Pull and hold brake release cable
Description	Launching will start by pulling the brake release cable. If it starts before getting permission from ECC, the mission will be failed.
Aspect	Description of Aspect
Input	permission issued
Output	The lifeboat is in the water
Precondition	The engine is turned on
Control	Pull the cable without stopping Check the indicator color

Name of function	Lower w/o stopping
Description	The cable should be pulled smoothly without stopping.
Aspect	Description of Aspect
Output	Pull the cable without stopping

Name of function	Check the hydrostatic indicator
Description	Changing the color of the indicator means the boat is in the water, and the hook can be released.
Aspect	Description of Aspect
Output	Check the indicator color

Name of function	Release the safety pin
Description	The safety pin should be released as soon as the boat is in the water.
Aspect	Description of Aspect
Input	The lifeboat is in the water
Output	The hook is free to release
Precondition	Hydrostatic indicator changed

Name of function	Release the hook
Description	The hook should be released as soon as the boat is in the water. The safety pin should be released first.
Aspect	Description of Aspect
Input	Hook is free
Output	Boat is free

Name of function	Release the hook
Description	The hook should be released as soon as the boat is in the water. The safety pin should be released first.
Aspect	Description of Aspect
Input	Hook is free
Output	Boat is free

Name of function	Move the throttle
Description	The lifeboat is in the hazard zone. The trainee should move the boat so fast to avoid a collision with the platform
Aspect	Description of Aspect
Input	Boat is free
Output	Drive the boat

Name of function	Drive away to the safe zone
Description	Heading to the safe zone is the first priority after launching.
Aspect	Description of Aspect
Input	Drive the boat
Output	Contact ECC
Control	assess currents assess direction

Name of function	Assess wind and wave direction
Description	Choosing the wrong heading without assessing wind and wave direction can lead to a collision with the platform
Aspect	Description of Aspect
Output	Assess currents and choose the heading

Name of function	Control the heading and steering
Description	The ability to control the heading is an essential key to driving a lifeboat
Aspect	Description of Aspect
Input	assess direction
Precondition	Drive the boat

Name of function	Look for people, equipment or vessel
Description	Look for any sign of a PIW, vessel, or equipment by looking around or using the compass
Aspect	Description of Aspect
Input	Mission issued approach changed
Output	Find the target

Name of function	Approach the PIW

Description	Getting close to the PIW with a suitable speed and direction. Be careful not to make a collision with PIW
Aspect	Description of Aspect
Input	Decision made on speed for approaching Decision made on the direction for approaching
Output	Get close to the PIW

Name of function	Pick up PIW
Description	Maintaining position for around 5 seconds to pick up the PIW
Aspect	Description of Aspect
Input	Position maintained
Output	PIW is in the boat Contact ECC

Name of function	Approach the life raft
Description	Getting close to the life raft to connect the painter for towing it or recovering passengers
Aspect	Description of Aspect
Input	Decision made on speed for approaching Decision made on the direction for approaching
Output	Get close to the liferaft

Name of function	Stop the lifeboat
Description	Maintaining position in the safe zone to transfer passengers to the recovery vessel
Aspect	Description of Aspect
Input	Position maintained
Output	Turn off the engine Transfer passengers

Name of function	Proceed to the leeward side of the rig
Description	Following orders and using the compass to get to the leeward side of the rig
Aspect	Description of Aspect
Input	Decision made on speed for approaching Decision made on the direction for approaching
Output	Get close to the platform
Control	Check the heading
Time	Proceed to the leeward side of the rig

Name of function	Deploy sea anchor
Description	Put the lifeboat in the wind direction and stop the boat to deploy the sea anchor
Aspect	Description of Aspect
Input	The engine is off

Name of function	Recover people
Description	The lifeboat needs to be maintained the position and attached to the liferaft to recover people from it
Aspect	Description of Aspect
Input	Painter secured
Output	Contact ECC

Name of function	Use the compass
Description	To find the location of the vessel or PIW, it is important to use the compass.
Aspect	Description of Aspect
Input	Location is defined
Output	Check the heading

Name of function	Secure painter to life raft
Description	Recovering people or towing the life raft can be done when the painters are secured to the life raft
Aspect	Description of Aspect
Input	Position maintained
Output	The lifeboat is connected Ready to transfer people

Name of function	Approach the vessel
Description	Choosing the best heading and speed to approach the vessel safely without make a collision
Aspect	Description of Aspect
Input	Made decision on speed for approaching Made decision on direction for approaching
Output	Get close to the vessel

Name of function	Move out of the rescue zone
Description	As soon as the PIW is transferred to the vessel, it is important to leave the rescue zone and drive to a safe zone
Aspect	Description of Aspect
Input	Passenger is transferred Mission issued
Output	Get out of the rescue zone

Name of function	Turn to the wind
Description	To deploy the sea anchor, the lifeboat should be in a downwind position
Aspect	Description of Aspect
Input	Got out of the rescue zone
Output	Check the wind direction

Name of function	Shift into neutral
Description	When the lifeboat is in the downwind direction, the lifeboat should be stopped to deploy the sea anchor
Aspect	Description of Aspect
Input	Wind direction checked
Output	Stop the boat

Name of function	Determine direction
Description	To approach the object, the trainee needs to assess the wind and wave directions to choose the best heading
Aspect	Description of Aspect
Input	Target found
Output	Make a decision on the direction for approaching
Control	Check the heading

Name of function	Determine Speed
Description	To approach the object, the trainee needs to assess the wind and wave directions to choose the best speed
Aspect	Description of Aspect
Input	Target identified
Output	Make a decision on the speed for approaching

Name of function	Determine speed/direction
Description	When the boat is so close to the object, the trainee has to choose the heading and speed carefully to avoid a collision
Aspect	Description of Aspect
Input	Got close to the liferaft Got close to the PIW Got close to the platform Got close to the vessel
Output	Maintain the position Miss the target

Name of function	Tow the liferaft
Description	The life raft should be towed gradually at a suitable speed to avoid being disconnected
Aspect	Description of Aspect
Input	The lifeboat is connected
Output	Contact ECC

Name of function	Change the course
Description	If the trainee feels he/she is going to make a collision or he/she wasn't able to catch the objective on the first try, he/she needs to change the approach
Aspect	Description of Aspect
Input	Missed the target
Output	Change the approach

Appendix II

Videos of FRAM signatures

Launch a lifeboat

(a) Unsuccessful Performance

Unsuccessful-launch.avi
Double click to play the video

(b) Successful Performance

Successful-Launch.avi
Double click to play the video

On-water tasks

- **Scenario 1 (Stop by a vessel and transfer PIW)**

(a) Unsuccessful Performance

Unsuccessful- FRC.csv.avi
Double click to play the video

(b) Successful Performance

Successful- FRC.csv.avi
Double click to play the video

- **Scenario 2 (Pick up a PIW)**

(a) Successful Performance

Unsuccessful_PIW.avi
Double click to play the video

(b) Successful Performance

Successful-PIW.avi
Double click to play the video

Appendix III

The comprehensive FRAM model of the lifeboat operation