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Development of firefighting resource management centre design

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Abstract

This report presents the development of the firefighting resource management centre (FRMC) design. The FRMC encompasses the entire management of resources involved in a fire scenario, including training, fire-drills, the people involved in fighting the fire, how they are organised, their communication, their equipment and how they use it. Data has been collected through interviews, remote ethnography, and virtual walkthroughs. This report includes a presentation of the central functions of the FRMC analysed with the Functional Resonance Analysis Method (FRAM), how to use the FRMC FRAM to improve safety and presents the process of continuous improvement. The process of continuous improvement gives guidance on how to increase learning from fire drills through analysing recorded drills and improved debrief and reflections post-drill.

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Content

1 Executive summary

1.1 Problem definition

The LASH FIRE firefighting resource management centre (FRMC) is a concept that combines the information needs, technical solutions, and organisational and human resources needed for timely response in a fire emergency scenario. The contribution of the LASH FIRE FRMC is to describe key sociotechnical functions and their dependencies in fire emergency management, and illustrate how vessels can continuously develop their fire emergency responses. An organisation's FRMC can be described as follows:

> The FRMC encompasses the entire management of resources involved in a fire scenario, including training, fire-drills, the people involved in fighting the fire, how they are organised, their communication, their equipment and how they use it. The word "centre" in FRMC does not refer to a physical room or place, as it does in a safety centre; rather it is the metaphorical collection of all things central in firefighting resource management.

On the bridge during fire, several actors and technical systems collaborate to fulfil many parallel operational goals, but it is still difficult to achieve an overview of available resources and status. Existing formalised firefighting resource management procedures are largely actor-oriented, providing less of a systematic approach to organise and coordinate the different *functions* of firefighting operations.

This report focuses on two problems:

1) How can the functions that must be executed by the different actors and technical systems to fulfil the many parallel operational goals during a fire be understood and described?
2) How can the LASH FIRE FRMC work contribute to improved firefighting resource management and thus improved safety on ro-ro ship?

1.2 Method

Data collection was performed through interviews, remote ethnography and virtual walkthroughs. The main analysis method used in this report is the Functional Resonance Analysis Method, which was applied to create a model of all the functions in a Firefighting Resource Management Centre. Due to the COVID-19 global pandemic, data collection methods had to be adapted to fit travel restrictions and limited possibilities for being physically present on ships. Interviews were conducted over Microsoft Teams, and two adapted ethnography methods named "remote ethnography" and "virtual walkthrough" were employed using on-ship facilitators and wearable action cameras.

1.3 Results and achievements

The remote ethnography method has been created within the LASH FIRE project. The data collection used in this report has contributed to the development of and practical testing of the method.

The first part of the results section covers the development of a FRMC FRAM[1] model of central functions involved in firefighting resource management (Chapter 6). This development and the resulting generic model serve as a reference for a shared understanding of the common working environment, the tasks and tools at hand, and the work processes organising the functions in an effective and safe manner in all phases of fire management. The LASH FIRE FRMC helps to define and structure fire resource management, and provides a framework for the crew to identify the most

[1] FRAM is an acronym for Functional Resonance Analysis Method. The method is used to analyse complex sociotechnical systems. See Section 5.2 for a more elaborate explanation and demonstration.

promising areas for improvement. The second part concerns the process of continuous improvement (Chapter 7), where suggestions are given on how to improve the current fire emergency handling by better utilising drills, reflections and crew knowledge.

1.4 Contribution to LASH FIRE objectives

This report is contributing to LASH FIRE Objective 1, the objective of WP07 and specifically Action 7-C.

Objective 1: LASH FIRE will strengthen the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions addressing current and future challenges in all stages of a fire.

WP07 Inherently Safe Design: Reduced potential for human error, accelerating time sensitive tasks and providing more comprehensive and effective decision support, by increased uptake of human centred design and improved design of tools, environments, methods and processes for critical operations in case of fire.

Action 7-C: Develop and validate a firefighting resource management centre (FRMC) with improved design for critical operations in case of fire, reducing the potential for human error, accelerating time sensitive tasks and providing more comprehensive and effective decision support.

1.5 Exploitation

The results in this report can be used for organisational development through an increased understanding of the functions involved in firefighting resource management, as well as increased utilisation of fire-drills by treating them as organisational learning opportunities.

In addition to this, we intend to write two academic journal papers based on the results presented in this report:

- The Development of the Remote Ethnography Method
- Modelling the Firefighting Resource Management Centre using a Functional Resonance Analysis Method

2 List of symbols and abbreviations

ANT	Actor-Network Theory
DFC	Digital Fire Centre
FIRESAFE II	Second study investigating cost-efficient measures for reducing the risk from fires on ro-ro passenger ships. Link to project site
FRAM	Functional Resonance Analysis Method
FRAM FRMC	The model of the Firefighting Resource Management Centre created by applying the Functional Resonance Analysis Method
FRMC	Firefighting Resource Management Centre
IR	Internal report
LASH FIRE	Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-Ro Ship Environment
RCM	Risk Controlling Measure
Ro-pax	Ship type with both roll-on roll-off cargo and passengers
Ro-ro	Ship type with cargo type roll-on roll-off
SOLAS	Safety Of Life At Sea Convention
WP	Work Package
IMO	International Maritime Organization

3 Introduction

Main author of the chapter: Martin Rasmussen Skogstad, NSR

The LASH FIRE firefighting resource management centre (FRMC) is a concept that combines the information needs, technical solutions, and organisational and human resources needed for timely response in a fire emergency scenario. The contribution of the LASH FIRE FRMC is to describe key sociotechnical functions and their dependencies in fire emergency management, and illustrate how vessels can continuously develop their fire emergency responses. An organisation's FRMC can be described as follows:

> The Firefighting Resource Management Centre (FRMC) encompasses the entire management of resources involved in a fire scenario, including training, fire-drills, the people involved in fighting the fire, how they are organised, their communication, their equipment and how they use it. The word "centre" in FRMC does not refer to a physical room or place, as it does in a safety centre; rather it is the metaphorical collection of all things central in firefighting resource management.

Continuous development and re-evaluation of an organisation's FRMC will contribute to LASH FIRE objectives of improved design for critical operations, reducing the potential for human error, accelerating time sensitive tasks and providing more comprehensive and effective decision support.

This document reports the findings from data collection and analysis that contribute to developing the FRMC concept, and provides tools and examples to set ship crews on a path to improving their own FRMC. Chapter 4 (FRMC Background) introduces the FRMC concept. Chapter 5 (Methods) presents the data collection methods and analysis method used in this report. Chapter 6 (Improving fire management with FRMC) presents the model of the FRMC, describing key functions in fire emergency response. Chapter 7 (The process of incremental improvement) presents the in-progress guidelines on continuous improvement of firefighting response.

3.1 The development of the FRMC concept through the LASH FIRE project

The ambition to develop a Firefighting Resource Management Centre (FRMC) for roll-on/roll-off (ro-ro) vessels can be traced back to the results from the FIRESAFE II project, where delays in decision-making regarding activation of fixed fire extinguishing systems were put in relation with a lack of relevant and immediate accessible information, in combination with suboptimal coordination of other resources on the bridge (Leroux et al., 2018).

The view of the FRMC as a broad concept including many aspects relevant to fire safety has been constant, but our view on which aspects that should be focused on within the FRMC has changed during the LASH FIRE project. At the early stages of the project, a large part of the focus was given to the physical presence of the FRMC through a large touch-screen table-prototype intended to include and present novel information and decision support for a fire emergency scenario. The prototype was called the Digital Fire Central (DFC). The dominating role of the physical aspect of the FRMC can be seen in the LASH FIRE Grant Agreement (citation, with parenthesis removed):

> Development of a firefighting resource management centre design, located at or close to the navigating bridge, intended to play the role as the "vessel control panel" in fire emergency situations. NSR will study and describe the process for conducting firefighting resource management for the defined generic ship types. Based on survey, interviews and

> investigation reports, requirements for technology and information will be developed for the firefighting resource management centre. NSR will, with the support of RISE, develop guidelines for organization of the response in case of a fire emergency, with focus on collaboration structures and scalability. This will include internal as well as external resources for collaboration and coordination.

And, it can be seen in the first internal reports of Action 7-C. In *IR07.5 Definition of Conditions For Firefighting Resource Management Centre,* the FRMC and the DFC are discussed almost in parallel, with the DFC being seen as the main element of the development of an FRMC. The connection is also emphasised through that the report includes two chapters provided from WP4 and WP5 (*IR04.18 Firefighting Resource Management Centre Regulation Review*, and *IR05.22 Firefighting resource management centre requirements*) that focus on physical and technical elements of the FRMC, which are the elements that are most tightly connected to the DFC.

In *IR07.7 Technical and information requirements for firefighting resource centre design,* the definition had matured into:

> The ultimate goal of the FRMC is to create the best possible situation for personnel in a fire situation. A main component of the FRMC will be the interface that the personnel handling the fire will interact with. But the FRMC goes beyond just the system interface. The FRMC is defined as both the technical systems and the wider context in which fire is managed, including socio-technical factors such as human-machine interface, communication and cooperation.

Here the wider context is brought into the definition, but the interface is still seen as the main component. The wider context, the complexity of the FRMC and strong presence of the DFC in the FRMC can be seen in the Actor Network Theory diagram (Figure 2), which was developed at this time.

Since IR07.7, we have decided to separate foci between the prototype in Action 7-A, and focusing on the organisational aspects of firefighting resource management in Action 7-C, leading to our current description of the FRMC:

> The Firefighting Resource Management Centre (FRMC) encompasses the entire management of resources involved in a fire scenario, including training, fire-drills, the people involved in fighting the fire, how they are organised, their communication, their equipment and how they use it. The word “centre” in FRMC does not refer to a physical room or place, as it does in a safety centre; rather it is the metaphorical collection of all things central in firefighting resource management.

3.2 The FRMC Contribution

Every ship already has systems for organising their fire emergency response and for managing resources involved in a fire scenario, but as previous research (Leroux et al., 2018) has shown, it does not always work optimally, and thus has an improvement potential.

While the FRMC should not be seen as technology itself, it includes the use of technology, including several systems that are being developed in the LASH FIRE project, such as drones (developed as part of Action 7-C), the DFC (Action 7-A), Smart alert system localization for first responders (Action 6-C), and improved cargo information systems (Action 8-A) (Figure 1).

Figure 1. FRMC and related elements.

We believe that our best contribution to improving safety is providing tools and methods for crews to improve the way they fight fire themselves, how they are organised, how they communicate, which equipment they use and how they use it. This will be achieved through the development of the FRMC concept with guidelines on how to evaluate what they currently have and do in terms of firefighting, better reflect on current practices, and how to better learn from drills and exercises.

Safety improvements on ships are often pursued through technical means and physical equipment. Such approaches will have costs in purchasing, licensing, installation, maintenance and specific training. Other solutions require organisational adaptation or change, e.g. that participants are more engaged and learn more from drills and training, and that the organisation is willing to spend additional time on improving safety although the outcome is not always possible to predict in numbers. This can be challenging as the crews are not primarily fire fighters, meaning that the organisation has to focus on fire safety in parallel with a wide range of other tasks. Furthermore, organisational change processes are never ‘plug-ins’ that can be easily installed. Organisational change requires commitment and engagement, and may take considerable time to achieve.

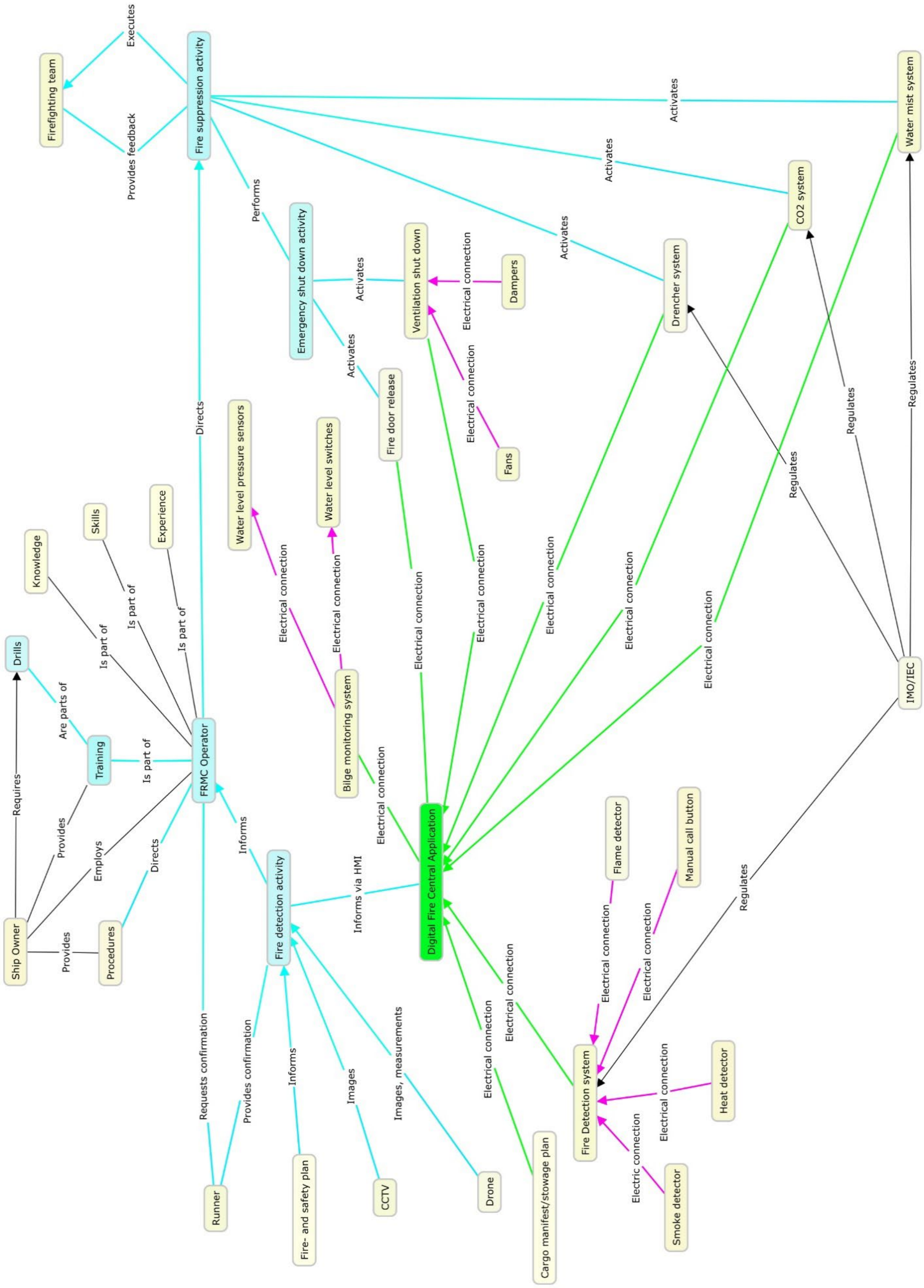


Figure 2. Actor-network theory diagram, from IR07.7

3.3 Sociotechnical systems and the value of models

Work on ships involves complex interactions between humans, machines and a dynamic environment. This type of work system can be defined as a sociotechnical system: technical and social (human and organisational) elements which are engaged in goal directed behaviour. The ship's overall performance and safety emerges from these countless interactions, and efforts to improve the work system requires *joint optimisation* of social and technical elements and subsystems.

Sociotechnical methods strive for work systems and technologies that are safe, that workers accept and that can be successfully integrated into organisations. Sociotechnical methods are important in safety work as they can contribute to a deeper understanding of how successful work is conducted, and how hazards can be managed. A gradual introduction of sociotechnical considerations into systems design can help organisations move from a technocentric view, to a more complete and realistic understanding of how technology and human/organisational factors interact, making it possible to identify new ways of supporting performance and safety.

However, it can be challenging to fully grasp the relationships between technical systems, the organisation and the people that carry out the work. Hence, it is important to find effective and practical ways to integrate sociotechnical considerations in safety work and in the technical systems' development lifecycle (Carayon, Hancock et al., 2015). The following section provides a rationale for the proposed FRMC approach, which centres around a generic model of the sociotechnical system involved with firefighting on board ro-ro vessels.

A system consists of several parts that interact to achieve a common overall purpose. For example, a ship in its entirety can be viewed as a technical system. Even though this technical system may be very large and complicated, a complete system description is possible, for example through technical specifications. Viewing a ship as a sociotechnical system, rather than a technical system, makes the picture more complete, but also more complex, as it includes the technical, social and organisational conditions in which the crew work to uphold safety and performance under variable conditions. The social and technical factors that contribute to overall system performance and outcomes can be hard to identify; there are often many, and some critical factors may be elusive.

While routine and highly regular work activities often can be understood and described in detail, this is more difficult for complex, collaborative work, or unplanned and irregular events, such as fires, where a high degree of expertise, creativity and flexibility is required. Attempting to specify all the interconnected parts and their behaviour is intractable, and to focus on individual components, or rely on descriptions of work as orderly sequences of events with predefined tasks and outcomes, risks eliminating important information about how work is successfully performed in safe and effective ways under real-life conditions (Waterson, Robertson et al., 2015).

Modelling has shown to be an effective method to study and represent sociotechnical systems, because a model can serve as visual support that enables multiple stakeholders to reason about a complex problem: how safety emerges from multiple, dynamically interacting factors in complex human-machine systems. The proposed FRMC FRAM model intends to clarify issues in the design of fire resource management, and can be used as a tool for reasoning about the work that needs to be supported for successful firefighting, as well as support work process change, or procurement and development processes. The model is a template that can be elaborated with a finer level of detail through participatory engagement among officers and crew members, technical development and other stakeholders.

4 FRMC Background

It has long been acknowledged that there is a need for improved integration of information systems and information, and improved organisation of the available technical and human resources on the bridge, in order to manage fires more effectively (Leroux, Mindykowski, et al., 2018). Many developments in later years can be seen as responses to this need, including concepts such as unified bridge, IMO's requirements for safety centres and more. The FRMC developments in the LASH FIRE project responds to the same call, and has connections to these aforementioned developments. However, rather than duplicating technical-material developments, the FRMC supplement existing solutions and work modes with organisational developments that:

a) provide a conceptual model of the bridge and its crew as a sociotechnical system
b) clarify the different functions that are carried out during a firefighting process
c) describe the preconditions for the functions to be initiated
d) describe the human, as well as technical, resources necessary for carrying out the function
e) describe the variability (with accompanied causes) on both function and system level
f) describe the dependencies between the different functions, and potential for functional/system resonance

Thus, these developments intend to support the organisation in its efforts to:

g) improve the work system (efficiency and safety) at the function level
h) develop more efficient procedures and practices for monitoring functions and functional resonance
i) redesign both organisational and technical configurations

Together, this conceptualisation of the sociotechnical system of fire management and its functions supports a shared understanding of the common working environment, the tasks and tools at hand, and the work processes organising the functions in all phases of fire management. The LASH FIRE FRMC work helps to define and structure fire resource management, and provides a framework for the crew to identify the most promising areas for improvement.

A lack of understanding of the sociotechnical factors involved in fire management can lead to a narrow focus on technological solutions, rather than focusing on its use and if/how it contributes to work processes. By not drawing on organisational perspectives and principles, technological-material developments and information-integrative developments are in risk of merely providing technical-material solutions to challenges that are *not* merely technical, as those challenges have significant organisational components as well. There are numerous examples of technical-material solutions to organisational problems in the maritime industry, and traces of those can be found in all the workarounds of technical systems needed to fit the work processes on the bridge. When, for example, systems for remote activation of drenchers from the bridge are in place and the crew are not making use of it, the discrepancy between technical opportunities and organisational arrangements may reflect either an unexploited technical opportunity or a sound organisational disposition. The LASH FIRE FRMC offers a conceptual description of functions and structures (linked functions) that the organisation (firefighting organisation level or company level) can use as a basis for improvement work.

Acknowledging the organisational dimensions is thus an entryway to understanding how the FRMC can contribute to improvement of fire resource management regardless of existing organisational or technical arrangements – regardless of whether the ship already has an integrated fire management system, a safety centre or the like. This makes the FRMC both a generic and scalable tool for optimisation and change.

5 Methods

Main author of the chapter: Erik Styhr Petersen, NTNU

In order to develop an understanding of fire emergency management abord ro-ro vessels we opted for interviews and ethnographic methods of observation. These methods were selected as they can provide rich descriptions of participants' thoughts and behaviours. Such data collection methods are well suited for achieving in-depth, contextualised, and nuanced information on a phenomenon.

5.1 Data collection

The data collection efforts for this work had to be altered due to the COVID-19 global pandemic, which limited our access to in-person interviews, observing on-board fire detection and alarm systems and observations of drills and training. This led to both the development of new methods and the identification of cases where research had been performed without the usual ethnographic methods of direct 'on-scene' observation (e.g. environments that require special training, space and access restrictions, economic restrictions or environmental considerations. See Hammersley, 1992; Hammersley & Atkinson, 2007). Since direct observation has been the prevailing way of understanding work conditions and processes (the 'context-of-use'), again being one of the core activities in Human Centered Design (HCD) (ISO9241-210, 2009), it is clear that usual application of observation needs rethinking or retailoring to cater for the unusual and/or unexpected.

For this reason, a significant effort has been put into formulating, and testing, viable alternative methods as a part of the LASH FIRE project, where both potentially future iterations of the DFC human-machine interface, as well as the design of the FRMC itself, is a data-driven processes following human-centred design principles. The ready availability of low-cost devices like smart phones and action cameras has made it possible to guide on-site persons to apply a few simple methods on their own, utilising sound and video-recordings concurrently. For this work, we applied two such methods:

- 'Virtual Walkthrough': Recording a walkthrough of the functions, usage and potential improvements of existing equipment, while conducting a narrative. This method is modelled as a Think Aloud exercise (Someren, Bernard, & Sandberg, 1994) .
- 'Remote Ethnography': Recording decision-making processes, use of equipment and information, teamwork, processes and procedures during comparable work situations, either in everyday situations or during drills. This method resembles the activities associated with the on-site visits typical for an ethnographically inspired process.

Both types of data collection were facilitated through a 'middle-man', employed by the company owning the site of interest, who acted as the go-between, connecting the site teams with the research teams. For parts of the data collection, researchers were also physically present during the recording sessions. As part of the work, we prepared instructions for the Facilitator, as illustrated in Figure 3. As described in these instructions, one of the responsibilities of the Facilitator was to support the Experimenter during the exercise, mostly by prompting in case the "thinking aloud" stops, by saying simple things like "Keep on speaking", or "Is there more to say about this function?", to help the Experimenter back on track. It was also very important that the Facilitator did not ask leading questions, injected personal opinions, offered advice or even corrections.

Fire safety systems demonstration

Facilitator's guide

DURING

Start by going through the Welcome letter with the participant. This letter contains the purpose and contents of the session. Then go through the grounds for consent, according to the form.

Set-up

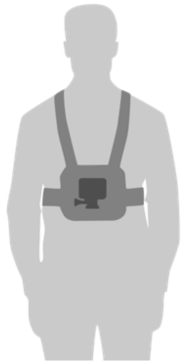
- Provide participant with Welcome letter
- Collect the participant's consent
- Rig camera equipment
- Start recording (and let it roll the entire session)

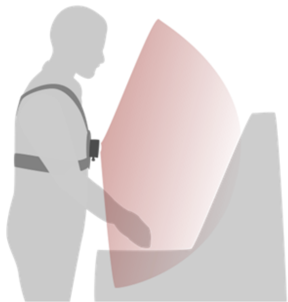
The session

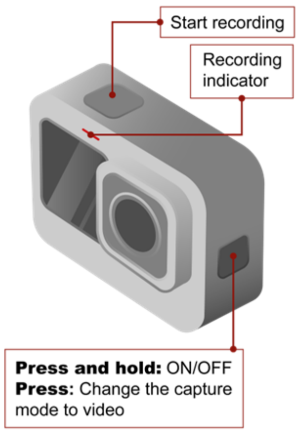
On the next page, you will find a list of what to ask the participant to demonstrate. Remember that the participant should demonstrate the system as if he or she was introducing a new colleague. See guidance in the bottom corner.

Wrap-up

- Stop recording
- Leave the Welcome letter with the participant and encourage them to get in contact if they want to add anything







Helpful tips:
You can say simple things 'Keep on speaking', or 'Is there more to say about this function', to help the participant back on track. It is however very important that you do not ask leading questions, inject opinion, offer advice or even corrections.

Any questions?

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Fire safety systems demonstration

Facilitator's guide

System walkthrough guide

Ask the participant to demonstrate and explain the following:

Bridge Systems

- [ ] Show from which location(s) a fire can be managed and what panels or equipment are relevant.

The Equipment

- [ ] Show me the **fire detection system**
  - [ ] What messages may occur in the alarm panel? What do they mean?
  - [ ] How do you tell where the detector is placed?
  - [ ] How do you see the status of a detector? (e.g. disabled)
  - [ ] What controls does the fire detection system have? (e.g. for acknowledgement or silencing of alarms)?
- [ ] [*if applicable*] Show me the **remote fixed fire suppression system** (drencher/ CO_2) for the roro spaces.
  - [ ] Show me how the suppression system is controlled.
  - [ ] How do you see the status of functions?
  - [ ] How do you find out what drencher zone or CO_2 compartment to activate?
- [ ] Show me the **fire and safety plan** and how is it used.
- [ ] Show me the **fire door panel**.
  - [ ] What controls does the panel have?
- [ ] Show the **communication devices** used during a fire incident.
  - [ ] What uses do different devices have during an incident?
- [ ] Show me an example of a **stowage plan.**
  - [ ] How is the plan taken into account during a fire?
- [ ] Show the **ventilation control panel(s)**
  - [ ] Show its functions and what you need to know in order to use them.
  - [ ] What are the 'standing orders' in case of a fire?
  - [ ] How are areas in the ship) described? Is this consistent with the fire detection system and suppression systems?

Other locations

- [ ] [*if applicable*] Show me the **drencher room**
  - [ ] Show any slave screens (alarm panels)
  - [ ] Show any GA and drencher zone drawings/writing
  - [ ] If applicable, show the switch for the pumps feeding the drencher system, and the switch for selecting water source (freshwater/seawater)

Any questions?

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Figure 3. Examples of the Facilitators guide to remote methods (Julia Burgén, RISE)

5.1.1 Interviews

The interview study involved in-depth, targeted interviews with 16 officers with roles and tasks in the firefighting organisation, mainly on the bridge and in the engine control room on ro-ro, ro-pax and vehicle carriers. In addition, interviews from LASH FIRE WP06 helped to shed light on the extended firefighting organisation on the vessels, making the number of interview informants close to 30. Interviews were mainly conducted digitally using Microsoft Teams, but a few interviews were conducted during onboard visits.

5.1.2 Virtual Walkthrough

Figure 4. A ship's officer performing a Virtual Walkthrough of the Fire Control Station

The Virtual Walkthrough method is meant to be a simple yet effective method, which is reflected in the instruction that were given to the Experimenter:

> *Perform the task and say out aloud what you do. Tell how functions work, and their purpose. Tell what you think about working with the device. If something is working very well, say so. If something is poor, be sure to tell it – and if you have any ideas about improvements, be completely sure to tell about it. It might be helpful to imagine you are giving an introduction to a new colleague – and above all, keep talking.'*

We found that this data collection method provided rich, detailed and solid first-hand impressions of the fire management devices on the ship. Figure 4 and Figure 5 are from the first of three Virtual Walkthroughs. Both are still photos from the video-recordings taken by the ship's crew.

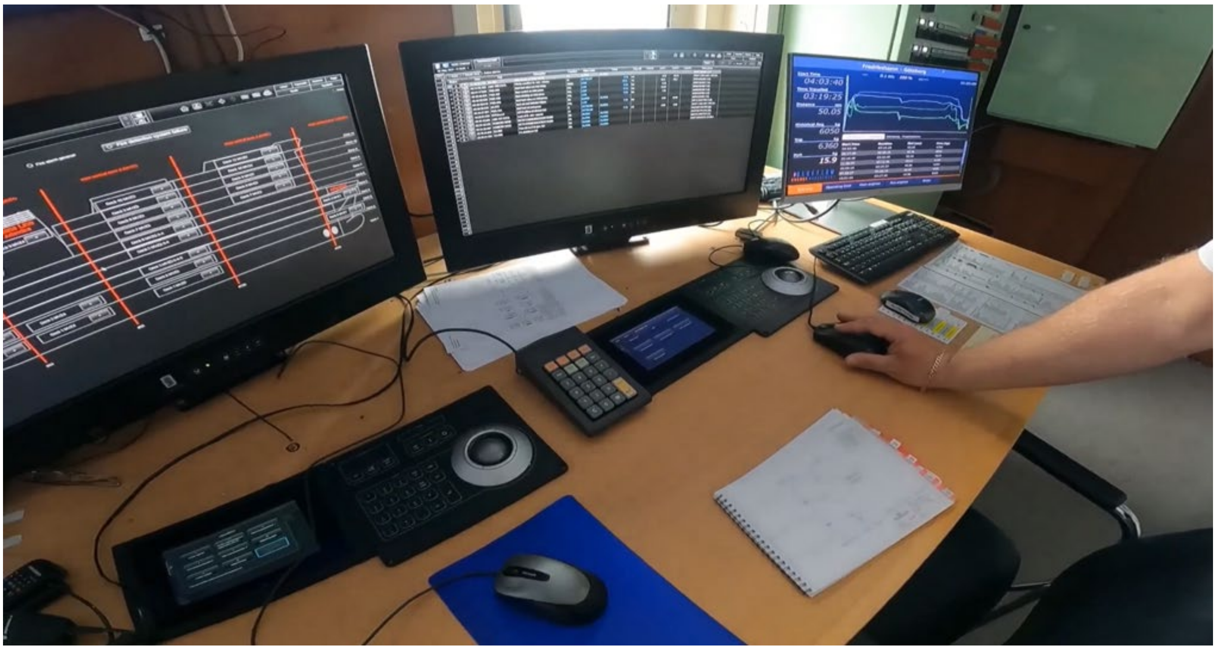

Figure 5. A ship's officer explaining the devices available for firefighting in the fire control centre.

5.1.3 Remote Ethnography

Ethnography does not have a standard definition (Hammersley & Atkinson, 2007), but the term is typically used when people's actions and accounts are researched 'in the field'. A trademark of ethnography is that the research concerns everyday contexts and that it takes place in the natural setting. This is important, because it means that no special attention should be put on the fact that recordings are taking place, or that design team members perhaps are virtually present. The same applies for remote ethnography, making the instructions simple:

> *Once the cameras are recording, be yourself and do as you always do. Try to forget that recordings are ongoing, and do not say or do anything out of the norm, driven by a consideration for the research[1]. In other words, act naturally and go about your business as usual.*

The remote ethnography was performed on three ships between May and October 2021. The data collection method was considered to be very successful by the research team as it provided rich data examples of human factors design, communication practices, procedures and work processes.

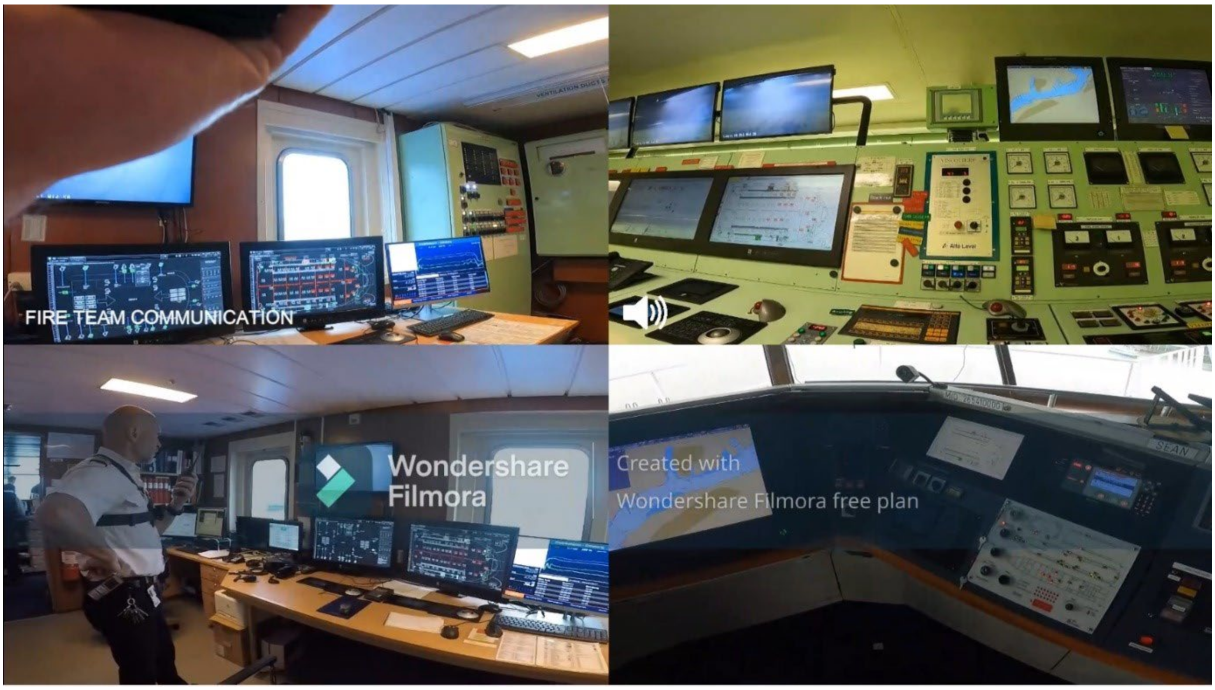

Figure 6. Concurrent picture-in-picture of four different recordings of a drill

5.2 Analysis

Sociotechnical systems analysis approaches are developed for complex, high-consequence domains, and provides perspectives and methods that support analysis, design, implementation and evaluation during work system change. This is a way to ensure that important social and organisational influences are considered during technological development, so that an investment will lead to intended work system outcomes, and new technology will be accepted and successfully integrated into organisations.

FRAM (Functional Resonance Analysis Method) is a method for modelling complex sociotechnical systems, as well as identifying vulnerabilities and areas with improvement potential with respect to both efficiency and safety (Hollnagel, 2012). The method is function-oriented, meaning that the system is described as a set of separate, but interrelated functions. Each function fills a sub-purpose of the system, and the work system’s performance as a whole depends on each of the functions, as well as on any resonance between functions. Thus, a good, empirically based system description will provide possibilities for identifying functions with improvement potential, as well as potentials for functional resonance, a phenomenon where variability/frequency of two or more functions[2] interact to produce escalating variation that may spin the system out of control. From there, one may implement measures to improve the system’s performance.

While FRAM in principle is an analytical model for task analysis, and can thereby be compared to other modelling frameworks, such as work domain analysis, FRAM is particularly oriented towards developing organisational resilience, resting on a significant theoretical foundation of resilience engineering (Hollnagel, 2012; Nemeth et al., 2009). One strength with this is that it provides theoretically informed methods to expand the descriptions of system functions with a number of functional aspects that are central for identifying the sources of variability in the system.

[2] Functional resonance does not have to result from interaction between functions. It can also be a result of interaction between functions and the system’s external environment, such as weather conditions.

Every function of a sociotechnical system in the framework of FRAM has a number of aspects that relate to the accomplishment of the function. These are (Table 1, Figure 7):

FRAM aspects	Description
Input	That which is used or transformed by the function to produce the Output, or that which activates or starts a function.
Preconditions	System states that must be [True], or conditions that ought to be verified before a function is carried out.
Resources	Something that is needed or consumed while a function is carried out. A Resource can represent matter, energy, information, competence, software, tools, manpower, etc.
Control	Control is that which supervises or regulates a function so that it produces the desired Output. Control can be a plan, a schedule, a procedure, a set of guidelines or instructions, a program (an algorithm), a 'measure and correct' functionality, etc.
Time	The various ways in which time can affect how a function is carried out.
Output	The result of what the function does, e.g., the result of processing the Input.

Table 1. FRAM aspects and descriptions

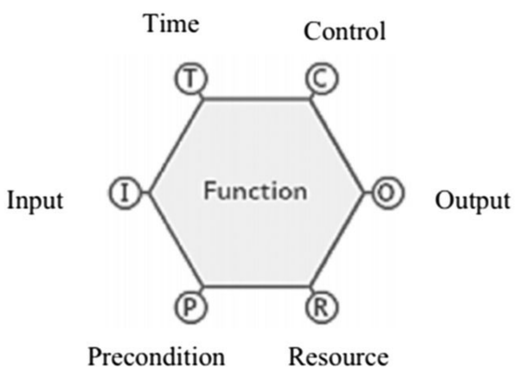

Figure 7. Aspects of a FRAM function

In other words, modelling and analysing a sociotechnical system with FRAM means identifying functions, their aspects and their connections. In our context of Fire Resource Management, a system model could look as follows:

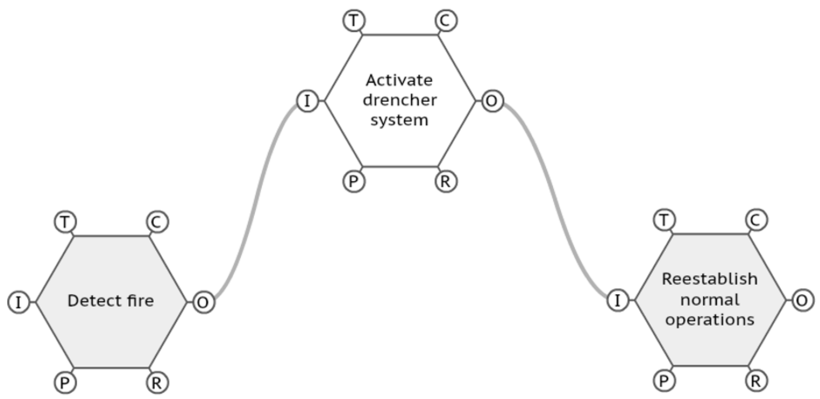

Figure 8. High level FRAM model

5.2.1 FRAM aspects for each particular function

For each of the functions, there will be one or more aspect that determine the contextual conditions for the function. For example, for the function *Detect fire*, relevant aspects include:

Aspect	**Description**
Input	Signal from fire detector
Precondition	Detectors in active mode
Resources	Well-functioning and user-friendly alarm panel Competent officer on watch
Control	Detector algorithm with suitable threshold and noise filter
Time	Detector delay (to filter out spikes and reduce false alarms)
Output	Informing fire organisation

Table 2. Example of function aspect for High level FRAM model

5.2.2 Variability

After having described the functions of the system at a suitable level for the purpose (different levels are possible, from high abstraction to high detail), one may start describing variability of each function, and subsequently the potential for functional resonance.

Functional variability refers to how the output of a function varies, due to any of the following: variability of the function itself (endogenous variability); variability of the work environment (exogenous variability); variability due to variability of upstream functions that provide Input, Precondition, Resource, Control, or Time for downstream functions. In our example above, endogenous variability could be the stability of the sensor, or the vigilance of the officer on watch, while exogenous variability could be weather conditions affecting the detector, or noise on the bridge affecting the audibility of the signal from the alarm panel.

5.2.3 Functional resonance

Following the principle of functional resonance, known from wave physics (Radi & Rasmussen, 2013), mutually dependent functions with their separate variability may cause functional resonance under circumstances where the variability frequency is similar, or where the frequency of function or system variability is similar to external variability (e.g. due to e.g. weather conditions, variabilities at ship scale, or other). The practical effect of functional resonance is escalating variability, eventually causing loss of control.

6 Improving fire management with the FRMC FRAM model

Main author of the chapter: Torgeir Haavik, NSR

6.1 Who is the FRMC FRAM for, and how can they use it?

The FRMC FRAM model presented in this report is developed to be generic, so that it may be useful in different types of ships, at different levels of the organisation. There may thus be different users of the FRMC, depending on the scope. Therefore, we recommend owners of work systems to conduct context-sensitive FRAM analyses to identify particular functions of fire management that can be strengthened.

Here, we suggest improvements of FRMC at two different levels, where the first level mainly involves the ship's crew, whereas the second involves people higher up in the shipowner organisation, as well as external partners. This span of use of the FRMC, to support both nitty-gritty functional development and more generic organisational capabilities, reflects the scalability potential of the FRMC.

6.1.1 FRMC first level improvement

To begin, we recommend owners of work systems to conduct context-sensitive FRAM analyses to identify particular functions of fire management that can be strengthened.

Through a FRAM analysis, the FRMC provides a common framework to identify particular functions of fire management that should be strengthened. Inadequate functions could be a result of lack of resources, substandard control mechanisms/artefacts, inappropriate temporal conditions and/or high variability. For these functions, particular needs may be identified and changes may be implemented by the ship crew themselves. These could relate to monitoring practices, communication practices, logging practices during drills or real fires, and much more. Moving one step further, the crew could also use the FRMC analysis to identify and monitor functional resonance, and decide on necessary measures to dampen certain sources of resonance, in order to safely maintain control under both normal operations and during a fire situation. Such measures may include minor material/technical adaptations, changes in human working conditions or organisational changes (e.g. division of labour or communication structures), and likely also combinations of these.

The first level FRMC improvement answers the question *"Are we doing things right?"*, as described by Argyris and Schön (1997).

6.1.2 FRMC second level improvement

The second step is to use the model to identify and design measures for improvement. While the first level concerned the question "Are we doing things right?", the second level involves asking "*Are we doing the right things?"*. As soon as we do that, we commit ourselves to reconsidering more fundamental organisational capabilities of the organisation and the sociotechnical system, and to facing the need to implement more fundamental changes. This could involve re-design of both organisational arrangements and technical configuration, and could potentially also require involvement of people further up in the onshore organisational hierarchy.

By organisational capabilities, we refer to resilience capabilities as portrayed by Nemeth et al. (2009) (see Figure 9), and which we later feed into the FRAM analysis (Section 6.3.4)

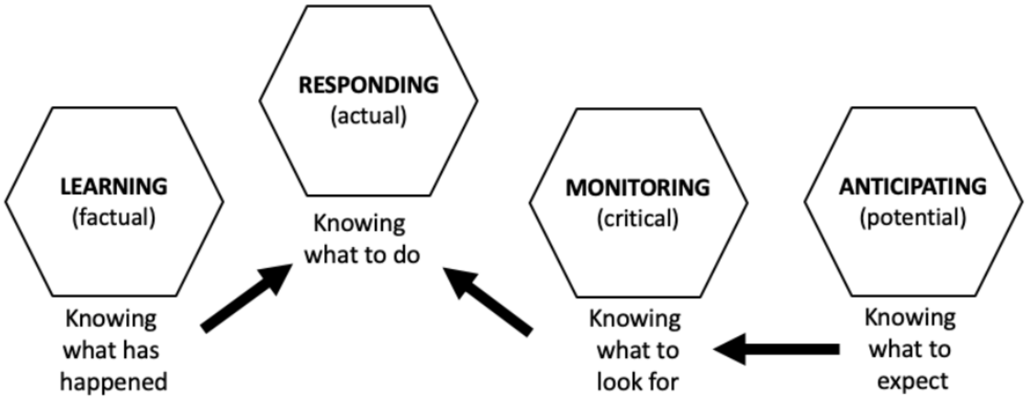

Figure 9. Organisational resilience capabilities

Further explanation and operationalisation of capabilities development is found in Section 7.2.2.

6.2 Using the FRMC FRAM framework

Building on the FRAM methodology, we have developed an FRMC framework that visualises and describes the fire management resources, and provides opportunities and guidance for incremental and continuous improvement of fire resource management in all types of ro-ro ships. Before presenting the guidance for improvement and change, we will present the stepwise process of the FRMC model development and analysis, before continuing with a description of how the FRMC can be used as a tool for improvement.

6.3 FRMC FRAM model development and analysis

6.3.1 Analytical stage 0 – current system

Fire resource management is generally governed by a combination of fire emergency plans, muster lists and non-documented established practices. Figure 10 shows an example of a typical fire emergency plan, commanded by the Safety Centre. While the size of the figure makes most of the content hard to read, the point here is that the instructions are largely *actor-oriented*, defining muster stations and main responsibilities for the fire task group, firefighting group, command group, engine group, etc. In the upper part of the instruction sheet, the ‘Fire emergency procedures’ can be found, stating in very few and highly abstracted sentences the main tasks associated with the steps of Rescue, Sound alarm, Extinguish (manual) and Limit. The actor-oriented muster list – in addition to the very brief Fire emergency procedures – does not say anything about the flow, order or dependencies of tasks, and gives only a static image over the actors with associated tasks.

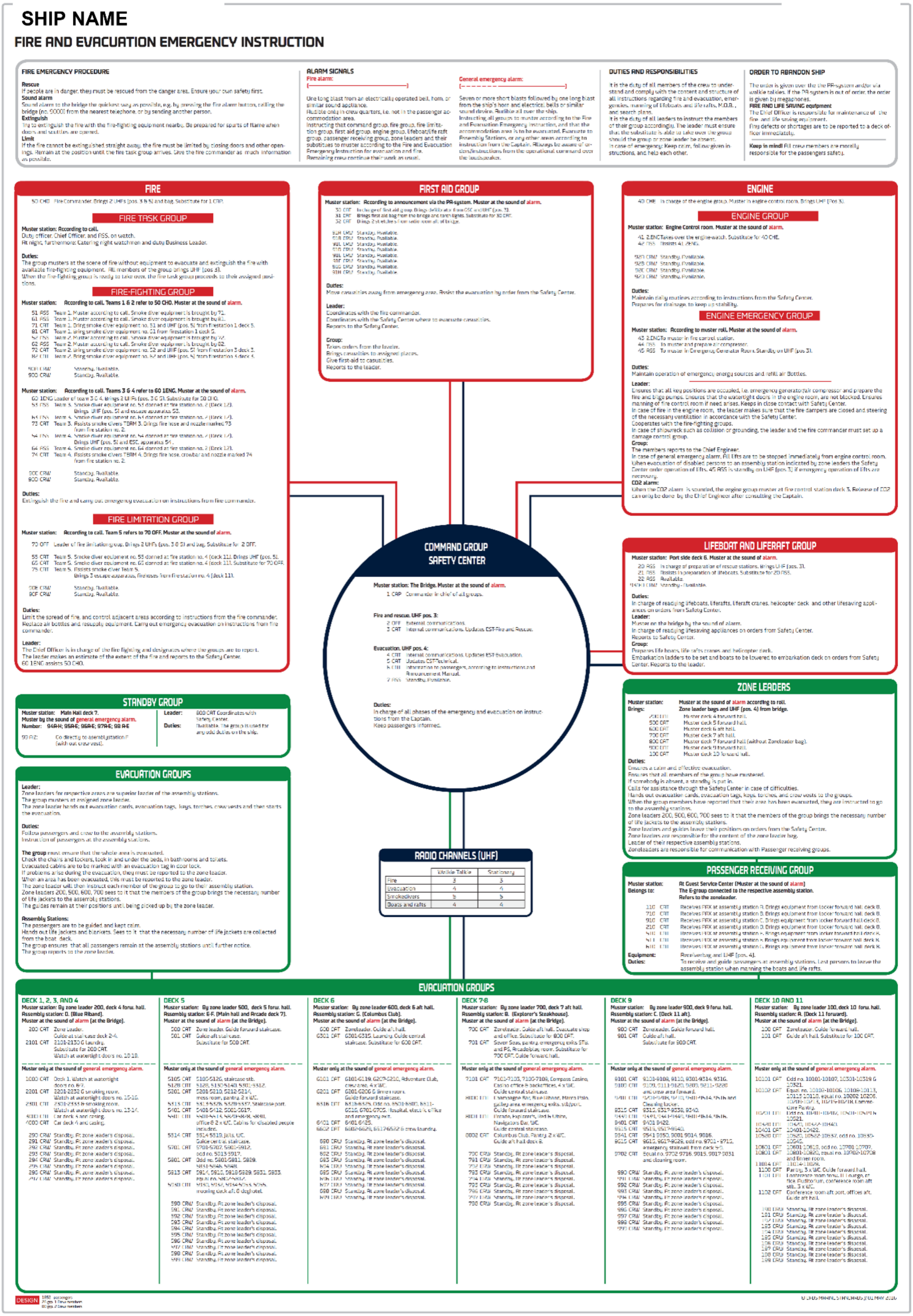

Figure 10. Example, fire and evacuation emergency instructions

In the following analytical stages, we develop a more structured (as well as generic) and elaborated model and analysis of fire resource management, which allows targeted intervention for improvement of a *dynamic* sociotechnical system, including the addressing of not only specific functions, but groups of functions, and further, *capabilities*.

6.3.2 Analytical stage 1

In the first stage of the FRMC development, the course of actions is described in a 'flat' manner, in the sense that there are no groupings of functions, only an indication or sequence[3] (see Figure 11; See ANNEX A for higher resolution images of FRMC analysis stages).

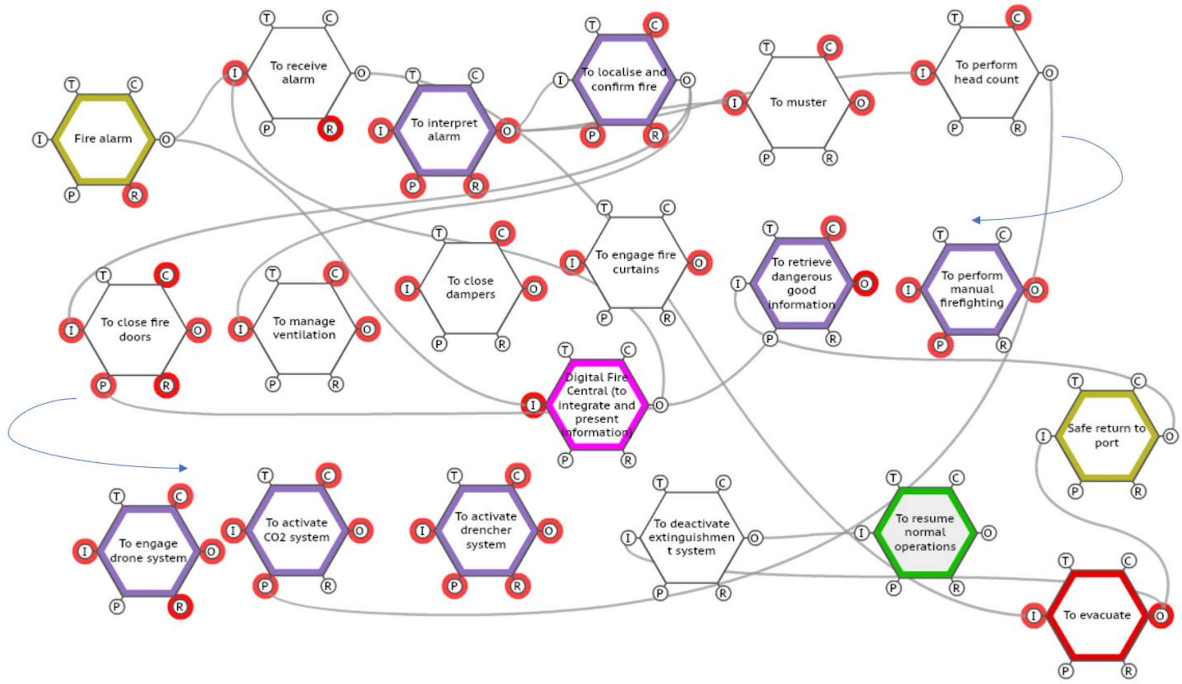

Figure 11. FRMC analytical stage 1

This portrayal of a dynamic sociotechnical process does not allow for considering *groups* of functions in a logical manner and should be considered only a first iteration system mapping to be subjected to analytical moderation in the subsequent steps.

6.3.3 Analytical stage 2

In this step of the FRMC modelling, we have grouped functions logically, based on analyses of both temporal connection and similarity with respect to theme and function level, e.g. grouping together background functions. For example, functions relating to closing of dampers and management of ventilation are grouped together as they are important not for the active extinguishment, but for controlling secondary conditions. The DFC is lifted out of the flow. A new temporal indication is included with the blue arrow (Figure 12).

[3] This FRMC model and the following are conceptual and generic. This means that they are not necessarily empirically exhaustive nor descriptive for each particular work system.

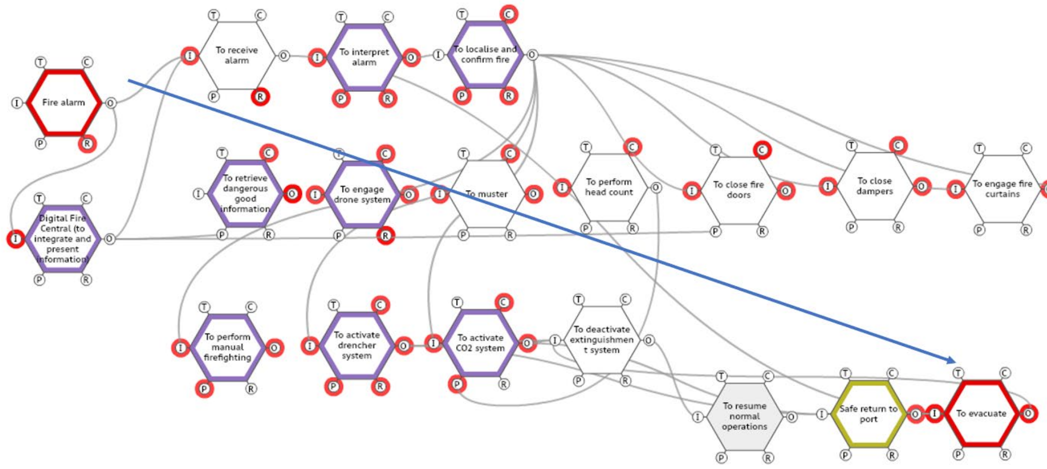

Figure 12. FRMC analytical stage 2

6.3.4 Analytical stage 3

Developing the analysis one step further, we see another layer of functions emerging that relate to organisational capabilities, including collective sensemaking, which tends to escape the more practical actor-task oriented descriptions of many of the existing fire emergency instructions (see e.g. Figure 10). The organisational capabilities identified in our analysis correspond to a large degree to the capabilities that are acknowledged as resilience capabilities in the literature of resilience engineering (Hollnagel, 2016): the ability to monitor and assess a situation; the ability to anticipate medium or long-turn development of a situation; the ability to respond to real-time and short-term developments of a situation; and the ability to continuously learn from both that which goes well and from adverse events. Figure 13 represents a 'full-fledged' ship-specific FRMC model that can be used for evaluation and improvement of fire resource management on ro-ro vessels and vehicle carriers.

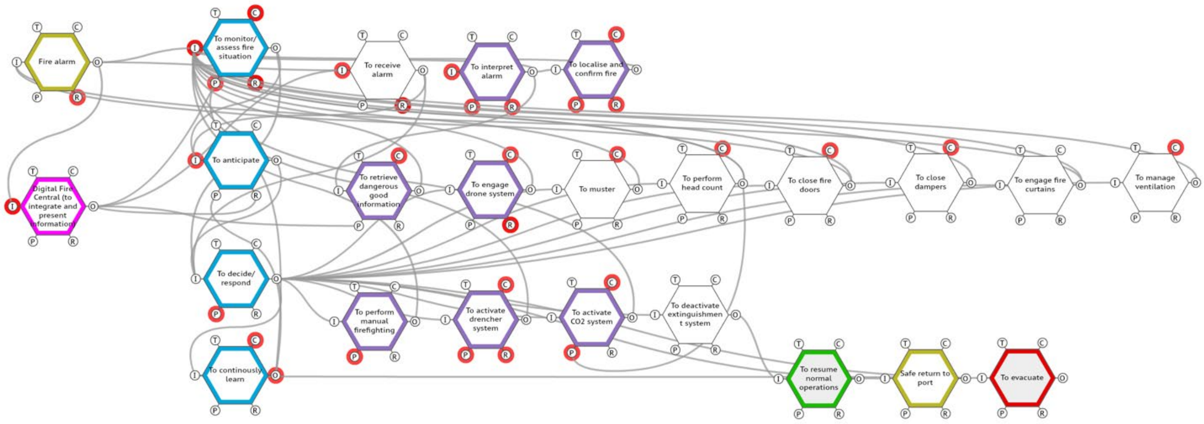

Figure 13. FRMC analytical stage 3

6.3.5 Analytical stage 4

At the fourth stage of the FRMC development, the different groups of functions, including innovative tools and the layer of organisational capabilities, are extracted from the background, lending themselves to a shared representation of, and language for, the fire resource management as a sociotechnical system, and as a tool for improvement. Figure 14 illustrates a generic FRMC with its associated LASH FIRE solutions.

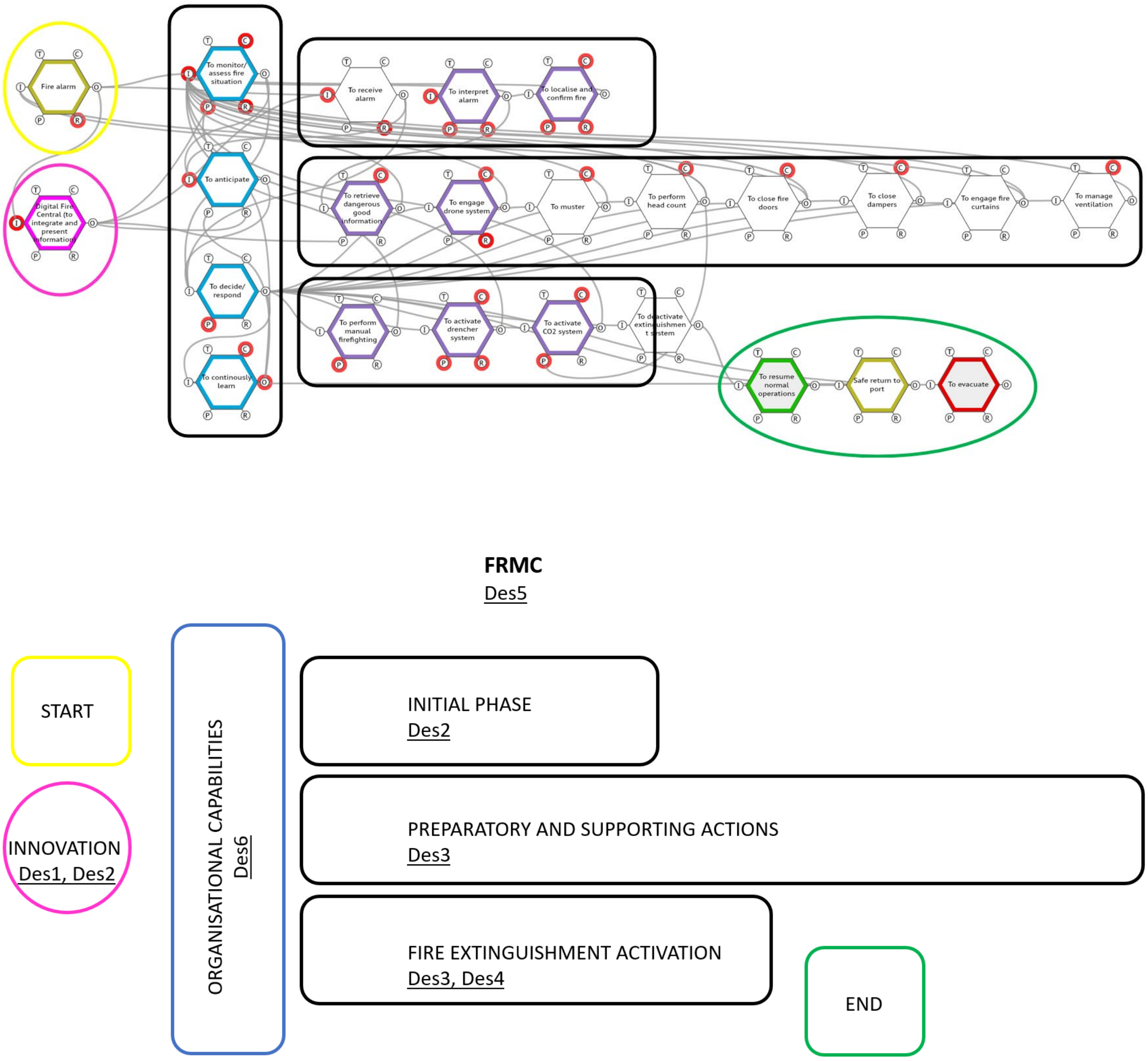

Figure 14. FRMC analytical stage 4.

This representation of fire resource management differentiates between different layers of *primary work processes*, *technological aids* and *organisational capabilities* respectively[4]. This allows for a higher degree of resolution when addressing the work system and identifying both weaknesses and strengths – and to implement improvements.

The black layer contains primary work processes, and are divided into the initial phase, preparatory and supporting actions, and core activities of fire extinguishing activation. The initial phase is supported specifically by the results from the development of an improved alarm panel with user-friendly interface – the "Digital Fire Central" – DFC (Des2[5]). Improvement of the fire extinguishing activation process is addressed by both the developments of improved procedures and design for fire

[4] Note that these categories need not be mutually exclusive, as, for example, technological aids also appear within the layer of work processes.

[5] Des2, Des3 etc. were project internal names of LASH FIRE solutions before they were turned into risk control options (RCOs) and subjected to formal safety assessment.

extinguishment activation (Des3), and the training course for extinguishing system activation (Des4) developed through LASH FIRE Action 7-B.

The DFC and the design process itself (Des1) are technological and processual innovations developed in LASH FIRE Action 7-A, and are represented by the pink layer.

The blue layer represents the cornerstones of resilience, and contain the organisational capabilities of fire resource management. The development of guidelines for organising the fire response (Des6) is a core initiative to strengthen the organisational capabilities of the FRMC.

With reference to the FRMC model stage 4 (Figure 14) or the FRMC model stage 3 (Figure 13), targeted improvement processes can be implemented in different levels of the organisation. Typically, stage 3 would be associated with nitty-gritty orientation at the crew level (functional improvement of primary work processes), while stage 4 would be a suitable tool for more generic development processes (capability and resilience development) higher up in the organisation.

In the following, we discuss how improvement potentials can be identified and addressed, both for specific functional improvement and more generic capability development.

6.4 Identifying and unlocking improvement potentials with FRMC

FRMC is both a mindset and a concept, and both functional improvement and capability development with FRMC requires that the FRMC modelling is first developed by those who are aiming for improvement. This reflects the researchers' experience that organisational development anchored in one's own practical context and experiences prove to be more viable (relevant and lasting) than ready-made organisational development principles based on a one-size-fits-all philosophy. This commits the end-users to invest time in the organisational development, in order to ensure context-sensitive adaptation. The alternative is to deploy the more generic models provided here as a point of departure. Although possible, it is likely that learning and suitability potentials will be reduced, as well as the sense of ownership and engagement. Too many organisational change processes have ended up unsuccessful due to lack of ownership and relevance.

6.4.1 Functional improvement

Functional improvement implies addressing individual functions of the primary work processes with the aim of optimisation, in other words: quicker and more reliable execution. The way the sociotechnical work system is modelled, each function has (as described in 5.2.1) a number of different aspects that can all be subject to improvement: input, output, resources, control, time and preconditions. Figure 15 shows a crude representation (analytical stage 2) of the FRMC work system (to the right), with the function "To activate drencher system" – encircled by a green line – in focus.

Aspects of that function are listed to the left.

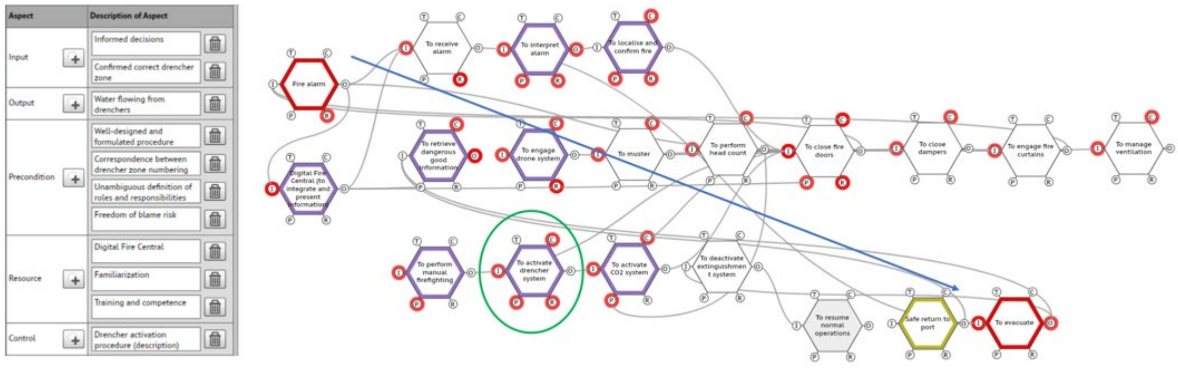

Figure 15. Functional improvement: to activate drencher system.

The function "To activate drencher system" involves the following aspects' factors (among others):

- Input
  - Informed decision
  - Confirmed correct drencher zone
- Preconditions
  - Well-designed and well-formulated procedure
  - Correspondence[6] between drencher zone numbering and fire detector numbering
  - Unambiguous definition of roles and responsibilities
  - Freedom of blame risk
- Resources
  - Digital fire central[7]
  - Familiarisation
  - Training and competence
- Control
  - Drencher activation procedure
- Output
  - Water flowing from drenchers

ANNEX B offers an example where all functions and aspects of FRMC analytical stage 2 are outlined in table format.

To continue the example analysis of the function "To activate drencher system", there are a number of aspect optimisations that the function may be subject to. Examples[8] include (suggestions in italics):

- Input
  - Informed decision
    - *Ensure that relevant and sufficient information is quickly provided*

[6] Direct correspondence, or via practical translation artefact or -process.
[7] Not a mandatory resource.
[8] Importantly, these are merely examples based on non-exhaustive studies of case vessels. The actual improvements must be identified on each ship, by members of the ship organisation themselves.

    - Confirmed correct drencher zone
        - *Improved communication between runner, fire commander on bridge and officer in engine control room opening the drencher valve*
- Preconditions
    - Well-designed and well-formulated procedure
        - *Improve wording of drencher operating instruction to avoid ambiguity and misunderstanding*
    - Correspondence[9] between drencher zone numbering and fire detector numbering
        - *Harmonise numbering of drencher and detector systems*
    - Unambiguous definition of roles and responsibilities
        - *Harmonise formal roles and responsibilities, and how they are practised*
    - Freedom of blame risk
        - *Work with organisational culture, address fear of blame explicitly*
- Resources
    - Digital fire central[10]
        - *Procure systems with high usability, developed with user centred design*
    - Familiarisation
        - *Improve familiarisation with drencher system among all crew members that are allowed to activate the system*
    - Training and competence
        - *Target 'learning', rather than 'checking the box', as the main rationale and outcome for drills and training courses*
- Control
    - Drencher activation procedure
        - *Re-design/re-formulate written instructions for drencher system so that they are clear and unambiguous*
- Output
    - Water flowing from drenchers
        - *Improve procedures for confirming that water is flowing from the right drencher zone*

Improving these aspects of this specific function will dampen the variability of the functions, meaning fewer human errors, strengthened organisational performance, and higher effectiveness of the function. Reduced variability of this particular function will also reduce the potential for functional resonance (see 5.2.1 for explanation of functional resonance).

Such a review can be done systematically for every function of the work system, with the aim to improve the efficiency of every function. At the same time, there will be certain functions with a higher improvement potential than others. These will be functions with a high variability (see 5.2.1.2-5.2.1.3), whose dampening will ensure a more predictable performance, both at function level and work system level. Although variability is a qualitative parameter not lending itself to one standard evaluation type, in the context of LASH FIRE, *time* is a central parameter that works well for the purpose of increasing the efficiency of fire resource management. For the identification of separate functions with high improvement potentials, it is therefore recommended to use temporal variability

[9] Direct correspondence, or via practical translation artefact or -process.

[10] Not a mandatory resource.

(i.e. the variation in time for successful execution of the function) as selection criteria for functions to be subjected to the improvement process (see Section 8).

6.4.1.1 Measuring time of functions

The variation in time used by a function from outset to finalisation can be determined in several ways. One possibility is to use expert judgment, based on experienced officers' estimations. While this may not be very accurate in terms of exact time measurements, it may provide good memory-based estimates valid for a long time span, including both normal and unusual function's performance.

Another possibility is to use video-based methods (see 5.1) to provide more accurate time measurements. This requires several realistic drills being video recorded over a longer time period, whereafter a systematic, function-oriented video analysis will provide the necessary overview over the temporal variability for each function. A challenge with this method is that it can be difficult to determine the start and stop of some functions; these moments may be vague, and the function can be executed more than once during a drill (for example, drenchers may be activated and deactivated more than one time). Advantages with this approach include more precise basis for the decision on which functions to improve, and the possibility of discovering function variabilities of which the crew are not aware.

6.4.2 Capability development

Approaching work system improvement as capability development implies increasing the level of analysis, from the functional level to the higher level of organisational capabilities. A central theme in the literature on organisational resilience capabilities is the balance between procedures and situated practise, often expressed as the relation between compliance and adaptability.

As Grøtan (2020) reminds us, safe and efficient organisational performance always combines elements of compliance with adaptation. This means that while procedures form the backbone of resilient performance, they must be sufficiently flexible to absorb the uniqueness of every situation, thus allowing for deviation from "strict compliance". In the TORC (Training for Operational Resilience Capabilities) framework of Grøtan (2020), the balance between following procedures and adapting to the contextual conditions is portrayed as in Figure 16.

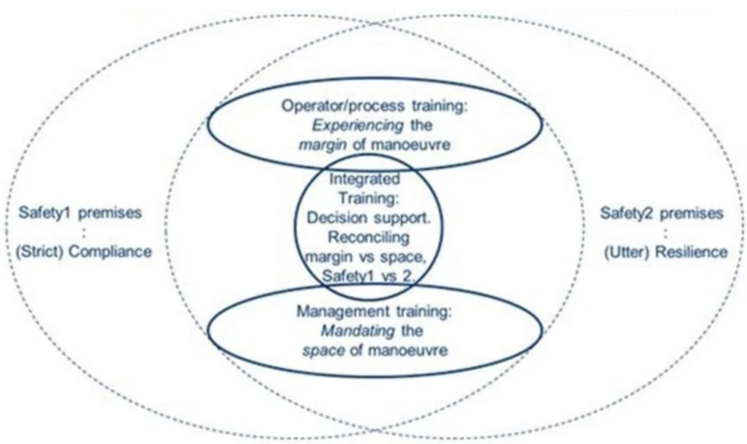

Figure 16. Operational resilience in the shadow of compliance. From: Grøtan (2020).

TORC training for decision-making and operational resilience involves exploring the space of manoeuvre in the interplay between operators and leaders under varying conditions. One thing that we can draw from this training approach and its underlying theoretical foundations, is the importance of forming procedures and guidelines in such a way that they leave a sufficient – although not too large – space of manoeuvre for crews, as well as leaders. They should provide unambiguous guidance for action, but at the same time allow for taking actions with the objective of responding to a particular situation, rather than checking off items in a procedure.

FRMC capability development implies developing practices and procedures of monitoring, anticipation, decision-making and learning that allow for a sound balance between compliance and improvisation, without risking blame for adhering too much or too little to procedures. While organisational resilience capabilities of monitoring, anticipating, decision-making and learning all rest on qualities of organisational culture, there is also significant support to be provided from innovative technological design (Figure 17).

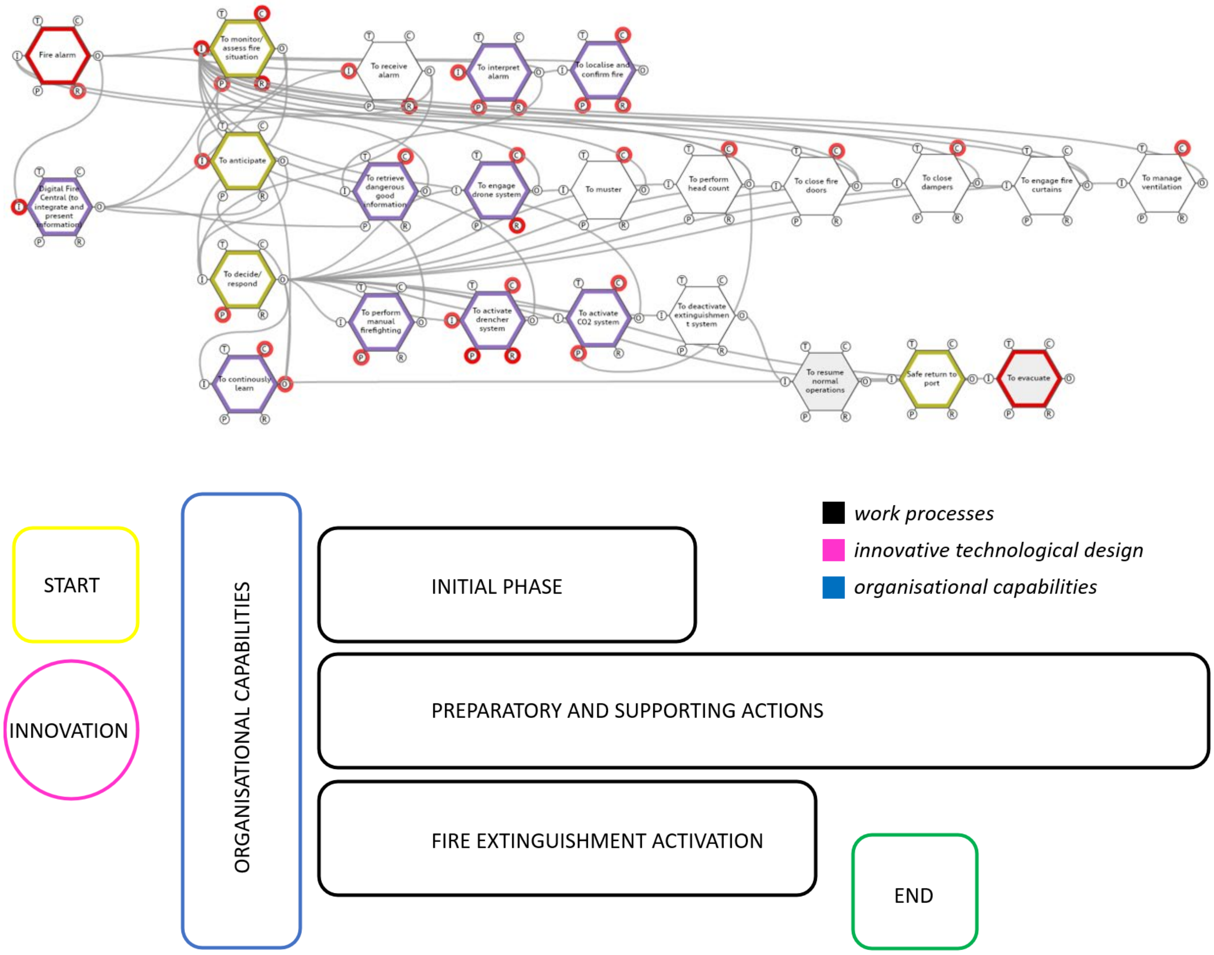

Figure 17. FRMC for capability development.

With innovative technological design, we specifically refer to the Digital Fire Central (DFC), which has been developed through LASH FIRE. The DFC was developed to support the sensemaking processes of monitoring, anticipation and decision-making during fire emergency management. The process of incremental improvement (see Section 7) developed in LASH FIRE therefore addresses the DFC design solution together with – and as an extension of – the organisational capabilities in the firefighting organisation onboard, by addressing the following challenge: *How can the DFC support the monitoring, anticipation, decision-making and learning in the particular work system onboard a ship, given how things are organised today, and how one wants things to be organised in the future*[11]?

[11] Organising principles span from 'command and control' to 'mutual adjustment', hence the DFC may play different roles in different settings.

7 The process of continuous improvement

Main author of the chapter: Martin Inge Standal, NSR

In this chapter, we will provide practical suggestions on how to utilise local knowledge to continuously improve the ship's FRMC. Figure 18 describes the process of using fire-drills for first- and second level FRMC development.

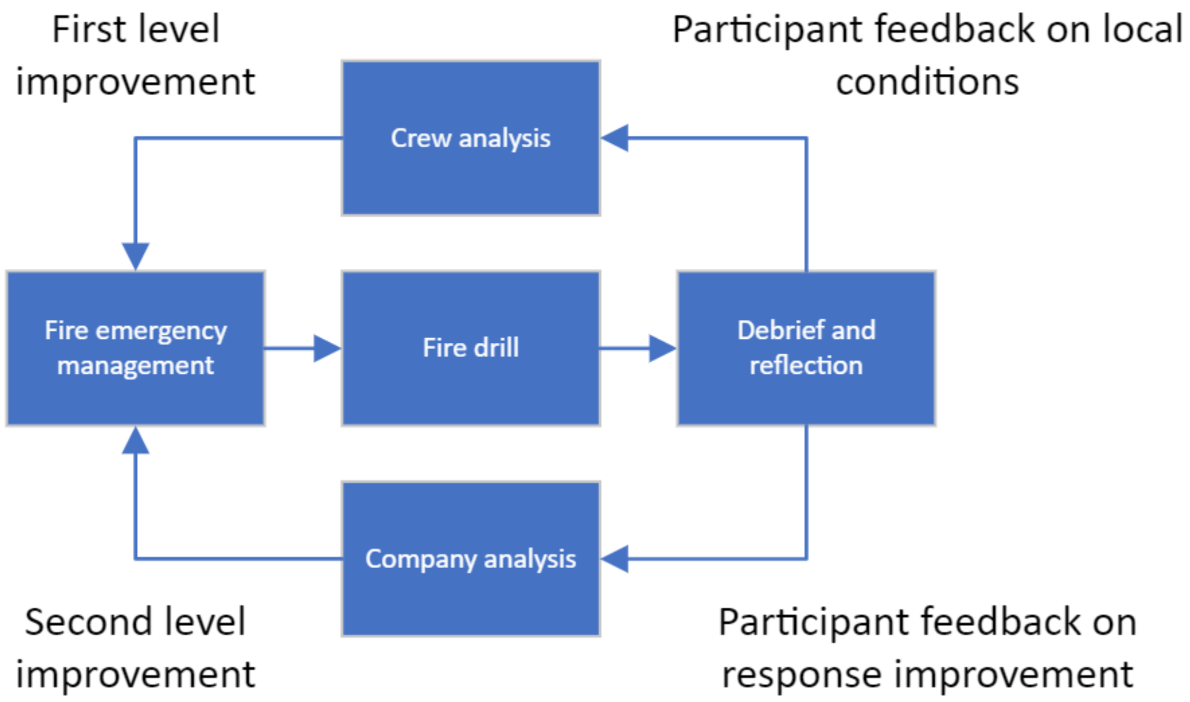

Figure 18. Process of continuous improvement.

As previously described, handling a fire situation requires a combination of knowledge of the local situation (e.g. the ship with its physical and sociotechnical aspects) and knowledge of fire and fire-fighting (Degerman & Bram, 2019). These aspects are connected to the organisational side of safety, such as the crew's knowledge, experience, and ability to adjust, cooperate and apply creativity, and are important for resilience and adjusting to a fire situation. After detection of fire on board ships, these types of knowledge are necessary for quick and appropriate fire emergency response, which again is essential for successful fire management, and to prevent loss of life and damage to ship and cargo (Leroux et al., 2018). Crew firefighting knowledge, ship familiarisation, experience and cooperation are enhanced through mandatory fire-drills as per the SOLAS regulation (IMO, 1998). SOLAS states that fire-drills must be performed every four weeks (IMO, 1998). However, the contents and learning outcomes of the drills are not well specified. The specific type of training and development that is needed in one ship may differ from another, and is dependent on the ship, crew and technical equipment.

Through the LASH FIRE project, we have identified improvement opportunities by combining existing mandatory fire-drills with the methods used and tools developed in the project. Crews can for instance utilise the FRAM-model of key functions and video-recordings of the fire-drills for continuous improvement of crew skills, and for improving ship-specific guidelines and procedures. In this section, we will provide some general recommendations for team-debrief and reflection, and supply examples from the data collected in LASH FIRE.

There is robust evidence spanning several decades that guide team self-correction training, such as debriefs or after-action reviews, encouraging teams to discuss and learn from recent events (Allen et al., 2018). Structured team debriefs have been shown to improve team performance. Such interventions should promote active self-learning, focus on specific events, and have multiple information sources to achieve the greatest effectiveness (Tannenbaum & Cerasoli, 2013). Furthermore, the way training is delivered is also important, where simulation- or practice-based training show the strongest evidence of effectiveness (Buljac-Samardzic, Doekhie, & van Wijngaarden 2020). Team-debrief is an inexpensive technique, which, when applied correctly, can improve the performance of the team (Reyes, Tannenbaum & Salas, 2018). The best teams learn from their experiences, self-correct and make adjustments (Reyes, Tannenbaum & Salas, 2018). As input for team-debriefs and active self-learning, it is best to capture attitudes, behaviours and cognitions of teamwork. An example of this is shared mental-models, which indicate whether team-members are on the same page (Salas, Reyes & Woods, 2017).

As mentioned above, different and changing environments, requirements and technology means that any guidance has to be flexible and be modifiable by the crew on the ship. Any effort for improvement need to be contextualised and adapted to the situation at hand, for instance fire emergency response (Salas, Reyes & Woods, 2017).

To summarize, using existing drills with focus on key functions described in the FRAM model, together with video-recordings, as a starting point for debrief sessions when the drills have been concluded could be a sensible and cost-effective avenue for continuous improvement of a ship's fire resource management. Using crew feedback and video-recordings can increase team knowledge and build shared mental models. The discussions that emerge from these drill debriefings can also be used to improve existing procedures and guidelines (e.g. markings, signage, written descriptions, documents), or identify areas where current practice or information are lacking or insufficient (e.g. information on the location or contents of cargo containers). Such information could be included in a digital fire central. Thus, results from drills, video-recordings, crew feedback from team debriefs and reflection can be used as input for company analysis, which again can be used for improving procedures, guideline, organisational, technical or equipment.

7.1 Practical guidance for continuous improvement using fire-drills

In this section, we will provide guidance based on decades of research on team improvement through debriefing. Reyes, Tannenbaum & Salas (2018) have compiled a list of best practices, which has been used as inspiration for this practical guidance.

7.1.1 Before fire-drill

- Consider when the drill is conducted. Fire drills should respect the rest and sleeping periods of the crew.
- Allocate sufficient time for debrief and reflection session after the drill.
- Inform the fire chief, captain or other key personnel why and how to lead a team debrief.

- Ensure that crew members feel psychologically safe (e.g. explaining that it is acceptable to not know something, to share unpopular ideas, or to speak out when they disagree with something).
- Keep in mind that the basic assumption is that all crew members are competent and well-intentioned, and that the debrief and reflection practice is about being even better and safer during a fire emergency.
- Consider using the functions identified in the FRAM-model to create scenarios where the factors for the node can be tested and discussed (inputs, preconditions, resources, control, time, outputs).
- Consider using body-mounted action cameras on key personnel to record drills. For instance, cameras on different personnel in different locations during the drill can be combined to have a continuous overview of the entire simulated fire situation. Having drills recorded to capture both good and sub-optimal practices can improve learning potential greatly.

Example starting point: "The fire-drills are an opportunity to learn from our experience. Let's look at how we handled this fire-drill: what we did well and what we could improve."

7.1.2 After fire-drill – team debrief and reflection

- Try to conduct the debrief close in time to the fire-drill.
- Avoid the "telling, not discussing" pitfall. For instance, the debrief leader should start the discussion by asking questions rather than telling the crew their opinions and experiences.
- Avoid being too evaluative. The tone of the debriefs should be developmental in intent ("Let's learn some stuff and make a few adjustments") rather than judgmental or evaluative ("Let's find out who is to blame for our problems").

Topics for discussion include how well communication, monitoring, coordination, conflict and planning was performed. Furthermore, the clarity of roles and assignments, and goals and priorities can also be examined.

Example starting point: "Let's consider how we worked as a team, in addition to any technical issues."

Example questions: "What happened? What did we do well? What challenges did we face? What could help us be more effective? Anything we need?"

7.1.3 Aftermath – using the results of the debrief and reflection exercise

- Record and circulate conclusions and agreements to eliminate misunderstandings or ambiguity, and to increase accountability.
- Conclusions and agreements can result in input for the next fire-drill or to start a process of changing organisational, technical or other aspects of the fire resources management (e.g., written procedures, technical aids, tasks or roles).

7.1.4 FRMC improvement examples from LASH FIRE data

Using the FRAM-model to focus on particular functions in drills and having active debriefing sessions, one can improve both the first level aspects of fire emergency response (doing things right) and develop suggestions for second level improvements (doing the right things). Below, results from the data collection and examples of improvements are mapped onto the FRMC functions capability development seen in Figure 17.

Innovation

Using data from interviews, discussions with crew, and video-recordings, potential for technological improvement was identified and a technological innovation in the form of the digital fire central was iteratively developed in LASH FIRE Action 7-A. Thus, companies themselves can use similar methods and information from debrief-sessions and video-recordings to identify potential for technical and organisational innovations.

Initial phase

Through our empirical study of the fire management organisation, we identified variations in available information presented in a way that is easy to understand and act upon. For instance, alarm signals, alarm locations varied from being immediately digitally available (e.g., on a digital map) to arbitrarily numbered with corresponding numbers in a physical map of the ship. Furthermore, lack of information about cargo (Action 8-A), which tasks have been started (e.g., manual closing of dampers), ship overview (e.g., ship zones and decks, drencher zones), timeline of events (e.g., how long since manual fire-fighting team was deployed), was rarely easily available. Such information needs could be identified through a debriefing session, and improvements can be made by integrating such information into the Digital Fire Central, which is developed in LASH FIRE Action 7-A.

Preparatory and supporting actions

Through the data collected we identified improvement possibilities regarding having clearer information, e.g. assisting drencher activation displayed in a digital fire central, such as placement of activated fire detectors and their corresponding drencher zones. Furthermore, clear and unambiguous standing orders that are in congruence with procedures and markings for drencher activation could also be identified by crew performing such a session. Similar solutions for improved drencher activation were also identified in LASH FIRE Action 7-B.

Fire extinguishment activation

Video-recordings and debriefing sessions can also be used to identify areas for second level improvement. For instance, by technical developments such as the DFC described above, or designing scenarios for more formal training from STCW partners. For instance, based on the data collected, training and reflection sessions for improved drencher activation are being developed in LASH FIRE Action 7-B.

FRMC and organisational capabilities

The ship's FRMC can thus be developed step-by-step by focusing on small organisational, structural and technical changes. For instance, ship-specific guidelines and procedures for fire emergency management can be continuously improved by using the tools presented in this report (FRAM modelling, video-recordings, and debriefing sessions). Suggestions for development of such guidelines are also being performed and tested in LASH FIRE Action 7-C.

Thus, the methods and data used to develop insight used for improvements in LASH FIRE (e.g., to develop the Digital Fire Central in Action 7-A, and Guidelines for extinguishing activation in Action 7-B), can thus also be used by the ships and crews themselves to continuously improve their firefighting resource management – i.e., their FRMC.

8 Conclusion

Main author of the chapter: Martin Rasmussen Skogstad, NSR

The objective of Action 7-C is to:

Develop and validate a firefighting resource management centre (FRMC) with improved design for critical operations in case of fire, reducing the potential for human error, accelerating time sensitive tasks and providing more comprehensive and effective decision support.

This report has presented the LASH FIRE FRMC design. The design goes beyond the physical items used in fire resource management and the physical place that it is managed from. The FRMC encompasses the entire management of resources involved in a fire scenario, including training, fire-drills, the people involved in fighting the fire, how they are organised, their communication, their equipment and how they use it.

This report presents several results that can have a positive effect on ro-ro fire safety. An improved and shared understanding of the functions included in firefighting offers a common reference for identifying weaknesses in current firefighting resource management. The process of continuous improvement presents a way of using existing drills, with focus on key functions described in the FRAM model, together with video-recordings, to organise debrief sessions with the aim of optimising functions or systems of functions. Using human resources and organisational processes that are already in place makes this a cost-effective avenue for continuous improvement of a ship's fire resource management.

The following steps in completing the objectives of Action 7-C are simulating, testing and validating the FRMC design and the tools made for continuous improvement of firefighting management on ro-ro ships. The setup for these steps will be included in D07.8 Design definition and development of firefighting resource management simulator prototype, followed by the results presented in D07.10 Deployment and validation of firefighting resource management simulator prototype, and D07.11 Firefighting resource management simulator prototype.

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10 Indexes

10.1 Index of tables

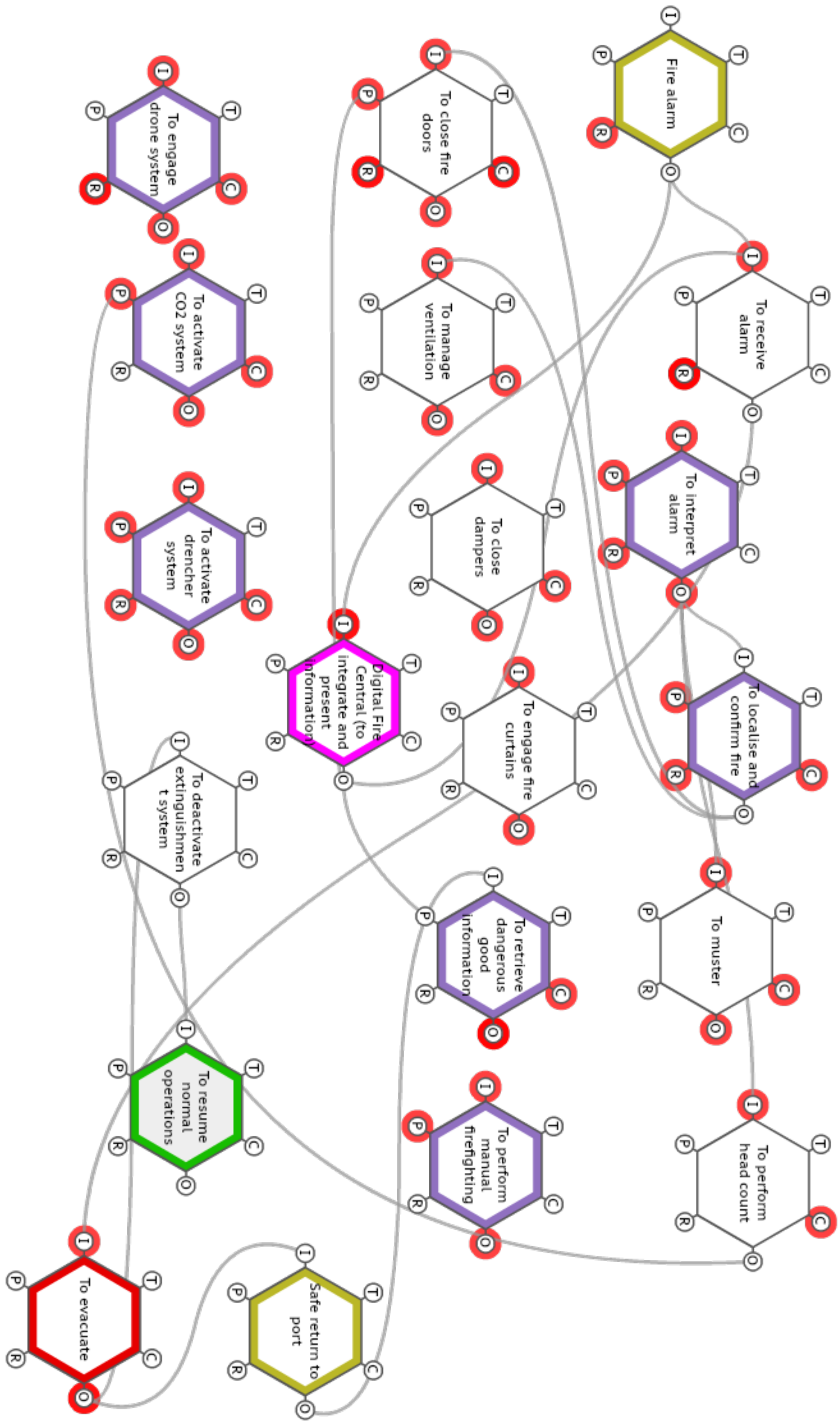
10.2 Index of figures

11 ANNEXES

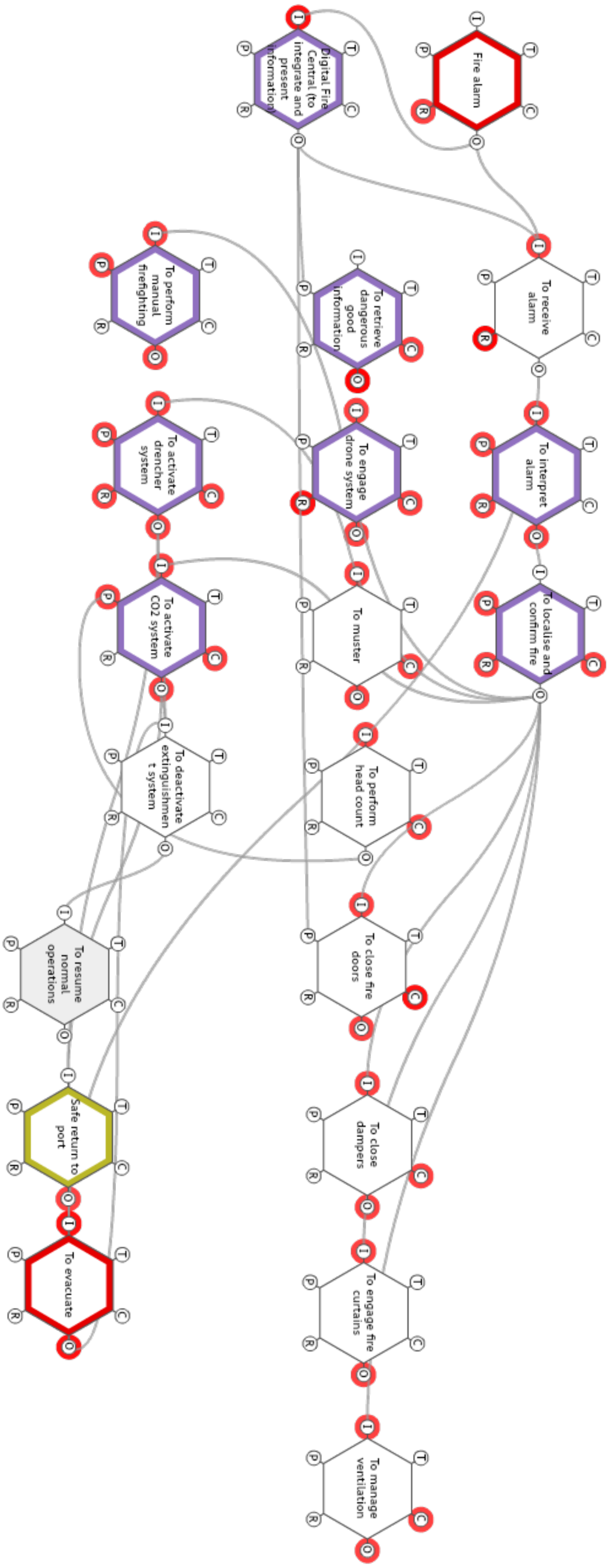
11.1 ANNEX A

FRMC FRAM models

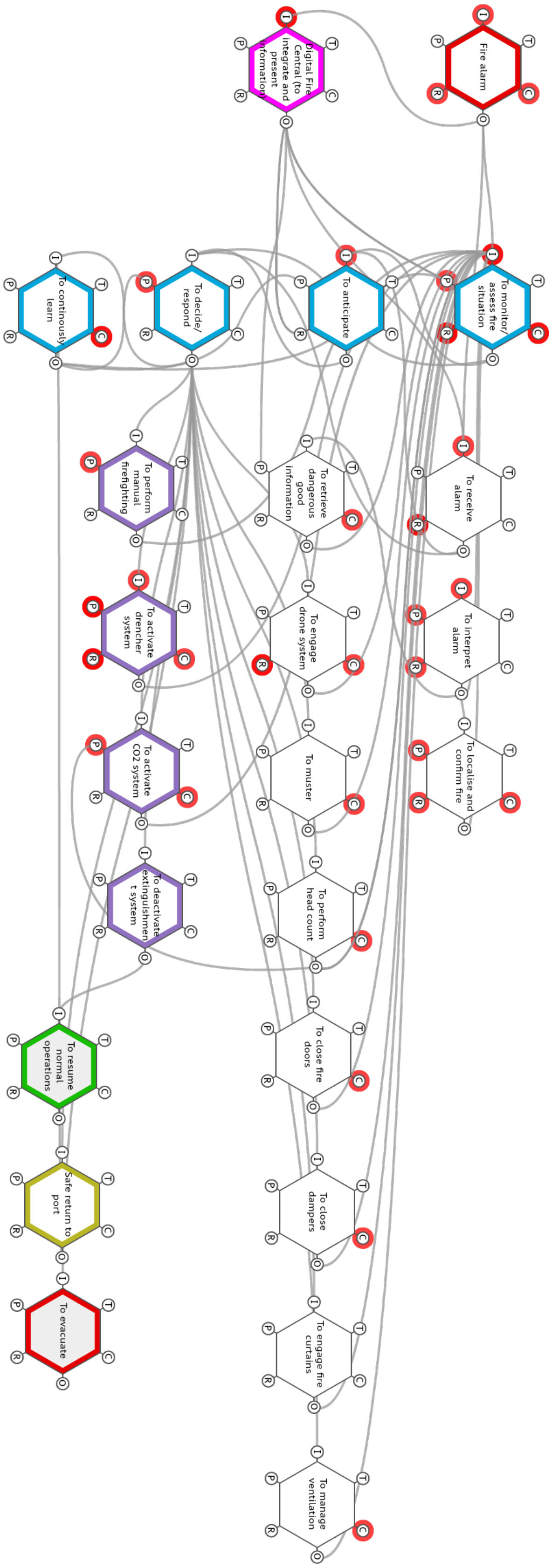
FRMC FRAM Analytical stage 1



FRMC FRAM Analytical stage 2



FRMC FRAM Analytical stage 3



11.2 ANNEX B

FRAM functions and aspects: analytical stage 2, functional improvement

Name of function	To receive alarm
Description	
Aspect	Description of Aspect
Input	Improved ind. and org. skills
	Signal on PA
	Updated information available
Output	Situation awareness
Precondition	
Resource	Drone system
	Fixed fire sensors
	Alarm panel
Control	
Time	
Name of function	To interpret alarm
Description	
Aspect	Description of Aspect
Input	Alarm awareness
Output	Alarm interpreted
	To check on dangerous goods
Precondition	Human centred designed alarm panel interface
Resource	Digital fire central
Control	
Time	
Name of function	To localise and confirm fire
Description	
Aspect	Description of Aspect
Input	Alarm interpreted

Output	Knowledge about location of fire
Precondition	Well-designed markings and signage
Resource	Runner
Control	Procedures for runner
Time	

Name of function	To activate drencher system
Description	
Aspect	Description of Aspect
Input	Informed decisions
	Confirmed correct drencher zone
Output	Water flowing from drenchers
Precondition	Well-designed and formulated procedure (description)
	Correspondence between drencher zone numbering and fire detector numbering
	Unambiguous definition of roles and responsibilities
	Freedom of blame risk
Resource	Digital Fire Central
	Familiarisation
	Training and competence
Control	Drencher activation procedure (description)
Time	
Name of function	To activate CO2 system
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	CO2 released
Precondition	Awareness of personnells whereabouts
	Well-designed and formulated procedure (description)
Resource	

Control	CO2 activation procedure (description)
Time	
Name of function	To perform head count
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Awareness of personnells whereabouts
Precondition	
Resource	
Control	Head count procedures
Time	

Name of function	To muster
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Personnel in right locations
Precondition	
Resource	
Control	Muster plan
Time	
Name of function	To deactivate extinguishment system
Description	
Aspect	Description of Aspect
Input	Control over fire
Output	Extinguishing successfully ended
Precondition	
Resource	
Control	

Time	
Name of function	To engage drone system
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Infrared camera information
Precondition	
Resource	Drones
	Drone operator
Control	Drone system procedures
Time	

Name of function	To engage fire curtains
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Water shield in place
Precondition	
Resource	
Control	
Time	
Name of function	To manage ventilation
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Limit oxygen to fire
Precondition	
Resource	
Control	Ventilation procedures

Time	
Name of function	To close dampers
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Limit oxygen to fire
Precondition	
Resource	
Control	Procedures for closing of dampers
Time	

Name of function	To continosly learn
Description	
Aspect	Description of Aspect
Input	After action review
Output	Monitoring capabilities
	Decision capabilities
	Anticipation capabilities
Precondition	Training
	Drills
Resource	
Control	Drills and debrief procedures
	Reflection, evaluation and change procedures
Time	
Name of function	To retrieve dangerous good information
Description	
Aspect	Description of Aspect
Input	To check on dangerous goods
Output	Confirmed dagnerous goods status

Precondition	Updated information available
Resource	
Control	Procedures for DG info retrieval
Time	
Name of function	To monitor/assess fire situation
Description	
Aspect	Description of Aspect
Input	Alarm interpreted
	CO2 released
	Water flowing from drenchers
	Awareness of personnells whereabouts
	Knowledge about location of fire
	Readily available information on dangerous goods
	Infrared camera information
	Fire and smoke stopped from spreading
	Main functions' status presentation
	Confirmed dagnerous goods status
	Water sprayed on fire
	Signal on PA
	Personnel in right locations
	Awareness of personnells whereabouts
	Limit oxygen to fire
	Water shield in place
Output	Situation awareness
Precondition	Monitoring capabilities
	Updated information available
	Continous feedback
	Integrated information

Resource	Digital Fire Central
	Drone system
	Tools and methods to maintain operational picture (e.g. whiteboard)
Control	Guidelines for organising the response
	Monitoring procedures
Time	
Name of function	To close fire doors
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Fire and smoke stopped from spreading
Precondition	
Resource	
Control	Procedures for closing fire doors
Time	
Name of function	Digital Fire Central (to integrate and present information)
Description	
Aspect	Description of Aspect
Input	Updated Dangerous Goods database
	Fire alarm
	Signal to alarm panel
Output	Updated information available
	Integrated information
Precondition	
Resource	
Control	
Time	

Name of function	Safe return to port

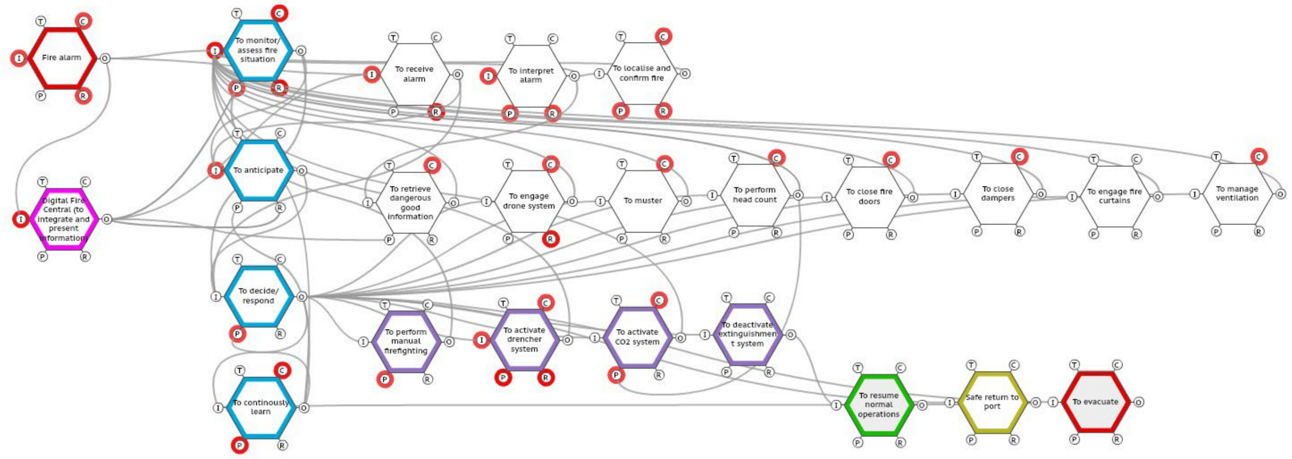
Description	
Aspect	Description of Aspect
Input	Control over fire
Output	After action review
Precondition	
Resource	
Control	
Time	
Name of function	To decide/respond
Description	
Aspect	Description of Aspect
Input	Situation awareness
	Identification of likely future states
Output	Informed decisions
	After action review
	Control over fire
	Necessary to leave ship
Precondition	Response capabilities
	Decision capabilities
Resource	
Control	
Time	
Name of function	To anticipate
Description	
Aspect	Description of Aspect
Input	Improved capabilities
	Situation awareness
Output	Identification of likely future states
Precondition	Anticipation capabilities

Resource	Updated information available
	Integrated information
Control	
Time	

Name of function	To evacuate
Description	
Aspect	Description of Aspect
Input	Necessary to leave ship
Output	
Precondition	
Resource	
Control	
Time	
Name of function	Fire alarm
Description	
Aspect	Description of Aspect
Input	Smoke in cargo space
Output	Signal to alarm panel
	Signal on PA
Precondition	
Resource	Reliable detector
Control	Technical protocols
Time	
Name of function	To perform manual firefighting
Description	
Aspect	Description of Aspect
Input	Informed decisions
Output	Water sprayed on fire

Precondition	Sufficient training on manual firefighting
Resource	
Control	
Time	

Name of function	To resume normal operations
Description	
Aspect	Description of Aspect
Input	Extinguishing successfully ended
Output	
Precondition	
Resource	
Control	
Time	


Fire alarm
To monitor/ assess fire situation
To receive alarm
To interpret alarm
To localise and confirm fire
Digital Fire Central (to integrate and present information)
To anticipate
To retrieve dangerous good information
To engage drone system
To muster
To perform head count
To close fire doors
To close dampers
To engage fire curtains
To manage ventilation
To decide/ respond
To perform manual firefighting
To activate drencher system
To activate CO2 system
To deactivate extinguishment system
To continously learn
To resume normal operations
Safe return to port
To evacuate