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Study and analysis of regulations, accident investigations and stakeholders for bridge alarm panel design

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Abstract

Previous research has shown that even though a ship may fulfil all regulations, crew activities related to fire safety can still be impaired by the design of working environments, equipment and system interfaces. Although a wealth of guidance exists on the integration of Human-Centered Design (HCD) principles into ship design, such design practices remain uncommon within the industry. There is a need of research that describes how the ship design and construction process can be augmented to better cater for fire safety-related operative needs, what barriers exist against HCD practices in the design of safety-critical artefacts, and how those barriers can be overcome. Given that the shipping industry adheres closely to regulation, regulatory studies is also a vital part of understanding the position of Human Factors and Ergonomics in ship fire safety design.

Based on results from the Firesafe II and SEBRA projects, one area of fire-safety related design that is in particular need of attention is fire alarm system interface design. The aim of this report is to research development needs in terms of usability and systems integration for fire alarm system interfaces and to turn this knowledge into design requirements that will inform subsequent conceptual and physical design of a fire information management system in LASH FIRE.

Research contributing to LASH FIRE D07.1 was conducted using qualitative methods, including document studies and interviews with crewmembers, employees of one shipping company land organization, a design firm, a classification society and three insurance / P&I organizations. Data was used to support a stakeholder analysis, a ship design process analysis, and a requirements analysis for fire alarm system interface design. Data from previous accident reviews was used to provide more information on how aspects of ship design may affect operative fire safety performance.

Studies have identified design process issues with regard to HCD introduction strategies, shipping company organizational practices, design process variance, project financing, project risk assessment, purchasing, forms of end-user involvement, site-team activities and support, shipyard base designs, change management, and shipping company market dynamics such as operational flexibility. Exploration of these issues will continue and form the base of future LASH FIRE organizational studies and development.

The regulatory analysis has showed that the current regulations and regulatory process combined with market and organizational conditions, have led to a focus on technical fire regulations. Usability and operational fire management are harder to audit and thus less complied with in the shipping companies. To meet the intentions of fire safety, one cannot ignore the design and operational phases.

The user needs and requirements for alarm system design point towards design solutions that integrate an improved fire alarm panel interface with an information management solution, thus providing the fire resource management system (FRMC) with necessary resources for information access and actuation possibilities. A need for thorough considerations of the balance between solutions that ’standardise use and work processes’ and solutions that provide leeway for contextual adaptation are advised. Issues that should be further explored and considered in that respect are consistence in the use of graphics and vocabularies, standardised data formats that allow other systems to connect, and sufficient affordance of systems to facilitate for sufficient flexibility in use.

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1 Executive summary

1.1 Problem definition

Previous research has shown that even though a ship may fulfil all regulations, crew activities related to fire safety can still be impaired by the design of working environments, equipment and system interfaces. Although a wealth of guidance exists on the integration of Human-Centered Design (HCD) principles into ship design, such design practices remain uncommon within the industry. There is a need of research that describes how the ship design and construction process can be augmented to better cater for crew needs related to fire safety, what barriers exist against HCD practices in the design of safety-critical artefacts, and how those barriers can be overcome. Previous research suggests that some answers may be found among the actors and activities of ship design and construction. In addition, given the emphasis on regulation in maritime safety, a second important issue is how the regulatory process and the nature of regulation may provide the best possible support for usability and ergonomics improvements in ship fire safety. Based on results from the Firesafe II and SEBRA projects, a third area of fire-safety related design that is in particular need of attention is fire alarm system interface design.

1.2 Technical approach

This report contains the results of a Stakeholder Analysis and Process Analysis, with concepts borrowed from Sociotechnical Systems Theory, investigating key attributes of the ship design process through a series of interviews. These analyses were performed in order to inform later research and development within LASH FIRE on HCD strategies and support.

Document studies were performed in order to investigate the contents and character of fire safety-related regulation, and to analyze the regulatory preconditions for increased HCD practice in fire safety design.

Research on fire alarm system interface design requirements was informed by field studies on ro-ro passenger ships, interviews with crews and literature studies. In parallel to this work, user tests of early-stage prototype developments have also informed and nuanced the understanding of how design can hamper or support maritime fire management. In addition, analyses of historical fire accidents were reviewed in order to find examples where aspects of ship and equipment design affected the outcomes of crew interventions.

1.3 Results and achievements

Results provide information on central design process stakeholders and process characteristics that will be pursued and utilized in later WP07 research and development, including both high-level organizational interactions such as class and insurance company influence, shipping company organizational practices around workplace interventions and technical changes, as well as design process activities and artefacts that could be modified to cater for end-user needs. The stakeholder analysis will be used to ensure that all relevant end-users of WP07 outputs are considered. Information on stakeholders and design process variance is essential to frame future interventions aimed at strengthening the influence of HCD in fire safety design.

The regulatory analysis has showed that the current regulations and regulatory process combined with market and organizational conditions, have led to a focus on technical fire regulations. Usability and operational fire management are harder to audit and thus less complied with in the shipping companies. To meet the intentions of fire safety, one cannot ignore the design and operational phases.

For the purposes of LASH FIRE technical development, this report prioritizes and develops the most acute design themes and issues around fire information and management systems design. From an array of design issues, the themes of integration and standardisation are brought forward. With respect to integration, the advice is that improved fire alarm panel interfaces are integrated into the information management solution that will provide the fire resource management system (FRMC) with the necessary resources for information access and actuation possibilities. Among the information types and actuation possibilities that should be considered to integrate into the FRMC system are location-specific temperature readings, cargo information, drencher information and management and fire-door management. Standardisation of design solution and the importance of balancing the way design may both ’dictate’ the user and provide leeway for contextual adaptation are discussed. Issues that should be further explored and considered are consistence in the use of graphics and vocabularies, standardised data formats that allow other systems to connect, and sufficient affordance of systems to facilitate flexibility in use.

1.4 Contribution to LASH FIRE objectives

D07.1 contributes to the following WP07 objectives:

“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.”

“Re-design and develop guidelines for improved fire detection system interface design, promoting intuitive operations and quick decision-making.”

”…increased uptake of human centred design and improved design of tools, environments, methods and processes for critical operations in case of fire.”

1.5 Exploitation and implementation

With continued development, organizational findings are expected to be turned into solutions that reliably support usability in fire safety design, boosting key activities in the ship design and construction process. Several actors stand to benefit from a stronger user-perspective in fire safety design– owners are rewarded with more robust and sustainable operations, and operative personnel benefit from of a safer, more efficient and more enjoyable working environment. Findings concerning the regulatory process and the nature of maritime regulations will be used to inform any project activities that may come to impact existing regulation. This information is also important in the continued collaboration with ship design process stakeholders.

When findings related to fire alarm system interfaces are materialised into better design solutions, reduced response time and improved decision-making processes in fire management situations is expected.

2 List of symbols and abbreviations

APV	Alternative Powered Vehicle
BAM	Bridge Alert Management
CCR	Cargo Control Room
CCTV	Closed-Circuit Television (surveillance camera)
FRMC	Firefighting Resource Management Center
GA	General Arrangement drawings
HCD	Human-Centered Design
HF/E	Human Factors and Ergonomics
INS	Integrated Navigation System
JCS	Joint Cognitive System
OOW	Officer of the Watch
RE	Resilience Engineering

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3 Introduction

Main author of the chapter: Staffan Bram, RISE

The technologies and environments used during onboard fire incidents have all been implemented through a ship design and construction process. While ship building is strictly regulated, previous research has shown that ships fulfilling all regulations may still display design solutions that impair crew activities throughout the fire sequence (Leroux et al, 2018; Bram et al, 2019). Design issues related to fire safety may already have existed in the original design of the ship, or they are the result of a continuation of retrofit or rebuild projects that is common within the ferry industry.

Although a wealth of guidance exists on the integration of Human-Centered Design (HCD) principles in ship design, use-centered design practice remains uncommon within the ropax domain. According to the researchers of LASH FIRE WP07, this situation indicates barriers against human-centered design practices in ship design, barriers that have not yet been fully understood.

Furthermore, even though regulation goes a long way to ensure a basic level of maritime fire safety, there is a risk of unintended effects when regulation is received and implemented in the industry (cf. Bram et al., 2019; Størkersen, 2018). The researchers of LASH FIRE have analyzed the regulatory process to find out how regulations and actors in the regulatory process influence design for fire operations.

A general challenge in connection to fire management on Roro-ships is that fire detection and decision-making is time-consuming, with the consequence that a fire may grow considerably before necessary measures are taken. Previous studies (Leroux et al, 2018; Bram et al, 2019) have identified the design of fire alarm system interfaces as one particular area of improvement. This report lays out the foundations for fire management system design that will be developed in later stages of LASH FIRE WP07.

4 Background

The starting point of LASH FIRE WP07 research is that fire safety design that incorporates Human-Centered Design principles can increase crew efficiency and effectiveness in the case of fire. A fire occurring in a tightly packed roro space may quickly outgrow the capacity of the ship fire crew, and a swift response is vital to ensure control. This means that all interventions that support crew fire-related activities, such as fire safety usability and ergonomics, are core ingredients in safety improvement (LeRoux et al 2018).

Firstly, previous research indicates that organizations involved in ship design and operation need support in order to safeguard usability in fire safety-related systems and environments. Secondly, this work needs to be backed by regulation that effectively reinforces operative fire safety-related needs (Bram et al 2019). Thirdly, there is a need of design guidelines and solutions for fire management support systems, with an emphasis on fire alarm system interface design.

In order to provide a background to the three areas of design processes, regulation and fire alarm system interface design, literature and state-of-the-art studies were performed within WP07. Results from these studies are reported in this chapter.

4.1 The ship design and construction process

Main author of the chapter: Staffan Bram, RISE

While previous research (Bram et al 2019) has shown that fire safety-related design issues originate from ship design process dynamics, there is currently a lack of information on what phases, interactions and other process aspects have the most profound effects on final design outcomes. Therefore, the purpose of organizational studies described in this report was to observe:

1. How crew needs related to fire safety are introduced and represented in current ship design and construction
2. Barriers that may undermine the impact of Human-Centered Design (HCD) principles on fire safety design.

To support this understanding, two complementing activities were carried out:

1. Stakeholder Analysis – This analysis aimed to identify stakeholders that influence ship design and construction outcomes with regard to Human Factors/Ergonomics for fire safety related artefacts. The primary purpose of this analysis was to examine stakeholder actions and interactions that may affect fire safety design. The secondary purpose was to identify actors that the project needs to interact with in future research activities.
2. Process Analysis – The aim of this analysis was to identify process characteristics that affect usability outcomes in the system of people and technology that ensures onboard fire safety.

The methods of stakeholder analysis and process analysis have several similarities, in that a stakeholder analysis normally incorporates some variant of process analysis, and that process analysis normally involves the description of process actor characteristics. Both methods are relevant for the purposes of LASH FIRE WP07 organizational studies.

4.1.1 Theoretical framework

The shipping industry has been described as a “complex sociotechnical system” (Mullai & Paulsson, 2011) – people and technologies that function together to pursue a variety of incentives and goals. From the global regulatory level and the financial dynamics of the world-market (Hetherington, Flin & Mearns, 2006), the shipping system can be broken down into national and regional contexts, fleets, organizations and individual ships. On the ship, the crew manages their work in a dynamic environment, with limitations both in resources and outside assistance. The work on board can itself be described as a complex system, resting on a high level of experience, skill and collaboration, involving the use of specialized equipment, tools and procedures (Sandhåland et al, 2015). When a fire occurs, the crew must fulfil several different roles and competing goals. In order for ship design to support this joint system of people and technology, it has been noted that crisis management on a ship must be approached from a holistic perspective (Soliman, 2013).

Systems theory originally arose as a concept in the 1950’s, with the aim of improving working conditions and productivity in the British coal industry (Trist, 1981). Studies of novel practices in mining suggested that work should be treated as a system, including both technical and social aspects (or sub-systems). Where the industry had previously designed work and organizations according to what technology demanded, Trist and his colleagues made observations suggesting a tight bond between people and artifacts. Workers, and the technologies they used, functioned as a joint system with particular goals, functions, inputs and outputs (Trist 1981). The idea of socio-technical systems has had a profound impact on modern-day studies of work and safety. One example is the profession of “Human Factors”. This discipline acknowledges a tight relationship between humans and their environment, i.e. that we can shape the environment to fit the needs of humans, but that humans will also adapt and change their behavior as a result of contextual changes. The interplay between people and their environment means that design should not only consider a local perspective (e.g. the work tasks of individual crewmembers), but that designers must also consider the effects of new design artefacts on the larger system of work tasks, people and technology.

While Trist’s approach to sociotechnical systems was to a large extent founded on ethical-political considerations of work to offer alternative developments to the prevailing perspectives on work influenced by Weber (bureaucracy) and Taylor (scientific management), more recent contributions to sociotechnical systems have also emphasized more ‘rational’ arguments for sociotechnical systems design and working modes. Here, aspects relating to cognition, variability and functional resonance provide further arguments to human-centred – but indeed holistic – approaches to socitechical systems design.

In cybernetics for example, which lies behind current socio-technical approaches to industrial safety (Hollnagel, 2014), systems are described in terms of a set of interdependent functions that work together towards common goals. The idea behind socio-technical approaches to safety is that organizations, activities and artefacts can be designed in ways that support people’s work and their contribution to safety, thus enabling not only user satisfaction and performance, but also more proactive safety measures. This is a contrast to traditional, reactive or control-oriented measures such as regulation, law-making and proceduralization (Hettinger, 2015).

When a sociotechnical research approach is applied, the work system is observed as a whole, with respect to its natural operational context. In order to provide a truthful representation of such a system, both activities, interactions, artefacts and social dynamics have to be factored in. Hollnagel and Woods (2005) set out to model this as *joint cognitive systems*. Here, they introduced ‘cognitive artefacts’, and under the more generic label ‘cognitive systems engineering, concepts like ‘mode errors’[1] and ‘automation surprise’[2] was coined (Dekker, 2019). A common methodology in five steps for sociotechnical systems analysis and change, with a focus on organizational processes, is described by Biazzo (2002):

1. An initial charting of goals, history, organizational structures, processes, functional inputs and outputs, social aspects and main variances
2. Technical analysis charting the main phases of the process at hand with key variances. Major deliberations, forums, participants. Information gaps, work activity problems
3. Social analysis – Network of roles, their effect on variances, psychological climate of the organization. Responsibility, Orientations and values, Important relations/co-dependencies
4. Analysis of external systems, which influence the main one
5. Work system design proposals.

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[1] Mode errors are joint cognitive systems breakdowns where the user loses track of the current system configuration (due to feedback of system state and activities) and executes an action in a way that would be appropriate in a different mode/configuration.

[2] The end result of a deviation between expectation and actual [automated] system behavior, that is only discovered after the crew notices strange or unexpected behavior and that may already have led to serious consequences by that time (De Boer and Dekker, 2017).

A key concept from Sociotechnical Systems Theory is variance. STS has its origins within industrial development and the original purpose of discussing variance was to identify disturbances in a production process that needed to be controlled in order to ensure a steady production output. As a contrast, under the heading of Resilience Engineering (RE), 'variability' has come to denote the natural occurrence of variations in any system and its context, stemming from emergent system and context properties that cannot always be reduced to controllable entities (Hollnagel et al, 2010). Rather than viewing variability as a target for control measures, RE emphasizes that people have a natural capacity to act on incomplete information and adapt to unforeseen events, and that variations in a process can also be tackled by providing operators with "requisite variety" in their actions – i.e. that they have the means to adapt to changes in the work context. The reference to requisite variety points to the cybernetical ancestry of RE, and Ashby's law of requisite variety: "[only] variety can destroy variety" (Ashby, 1956).

A consequence of this (positive) orientation towards variability is the opportunity to theoretically acknowledge the performance variability caused by pragmatic and necessary trade-offs between efficiency and thoroughness that are experienced in any thorough study of practical work in sociotechnical systems. Hollnagel (2009, 2015) uses the terms efficiency-thoroughness trade-off (ETTO) and work-as-done (WAD) to theorize origins of performance variability.

To operationalize this theoretical acknowledgement of performance variability into design implies to cater for affordance (Gibson, 1977) of the designed environment in ways that balance the need for standardization and accountability on one hand, and situational adaptation on the other. While this balancing act does not directly challenge established human factors design principles of e.g. Wickens (2014)[3] and Norman (2013)[4], it contributes with a WAD-theoretical perspective that is not fully elaborated and taken fully into account in much design literature (Fischer, 1999; Hollnagel, 2015). It is the ambition that the theoretical perspectives framing our research will add new arguments and incentives that may contribute to reducing the gap between maritime design research and guidance, and actual practice in ship design and construction.

Several concepts are used to describe different aspects of use-centered workplace design. In this report, the following concepts are employed:

Human Factors / Ergonomics (HF/E) – These concepts are often used interchangeably. The International Ergonomics Association defines them in the following way: "*Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance*" (IEA, 2000). Historically, Ergonomics was more concerned with physical factors such as anthropometrics and biomechanics, while Human Factors was more concerned with human cognitive abilities, organizations and human-computer interaction. In this report, 'fire safety HF/E' is used to describe sources of risk, inefficiency and ineffectiveness related to fire prevention and management, produced by ship design.

Usability – a quality attribute that assesses how easy user interfaces are to use (Nielsen, 1993). The concept has its origin in software and digital interface development. Usability is defined by ISO

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[3] Wickens' principles related to: perceptual operations; mental models; human attention; and human memory

[4] Norman's principles related to: discoverability, feedback, conceptual model, affordances, signifiers, mappings and constraints.

(2018) as ”*The extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*”

Human-Centered Design (HCD) – Defined by the IMO (2015) as “*An approach to system design and development that aims to make interactive systems more usable by focussing on the use of the system; applying human factors, ergonomics and usability knowledge and techniques*.”

The present study will approach ship design as a system of people and technology, working in an organizational and political context, in order to realize several, sometimes conflicting goals. As noted by Biazzo (2002), sociotechnical systems analyses may run the risk of representing reality in a way that is too simplistic and linear, as opposed to the often iterative, messy structure of work in the real world. Results from previous studies (Leroux et al, 2018; Bram et al, 2019) have suggested that ship design is a process that can take many forms, and where many sources of variability exist. The aim of LASH FIRE WP07 is to find ways of introducing Human-Centered Design concepts into Ropax fire safety design. For that to be possible, studies must closely reflect the different circumstances for user integration in the process.

4.1.2 Process mapping in a sociotechnical system

In his article from 2002, Biazzo discusses process mapping and organizational analysis from a systems-theoretical perspective. In the words of the author, the purpose of process mapping it to show the relationships between activities, people, data and objects involved in the production of an output. An analysis should show what the system does, what controls it, what it acts on, what means it uses to perform functions, and what it produces. In the most common methods, a process map is produced representing one of four perspectives:

- A functional perspective, showing activities and flows of information
- A behavioral perspective, showing when and how process elements are carried out
- An organizational perspective, showing where and by whom activities are carried out
- An informational perspective, showing the structure and relationships between informational entities that are manipulated

Biazzo argues that there is a distinct similarity between the concepts underlying process mapping and systems theory respectively – the organization is a collection of subsystems transforming inputs into outputs. As part of process mapping, the analyst will seek to understand both physical objects or artefacts, activities, methods and knowledge involved in process operation. However, the author also invokes the idea in Sociotechnical Systems theory, seeking a best fit between technological and social subsystems. If the process analysis is to contribute to improvements, analyses need to represent the social dynamics of organizations. Processes may involve actors with different interests and perspectives, and analyses should examine how artefacts in the process could be made to serve the needs of multiple stakeholders.

4.1.3 Stakeholder analysis

A stakeholder is any actor that affects, or can be affected by, a decision or action (Leventon et al, 2016). Stakeholders can include clients, project managers, designers, subcontractors, suppliers, funding bodies, users and the wider community (Newcombe, 2003). Identifying stakeholder needs and influence is vital for research that aims to affect the process of ship design and introduce new values and incentives. The purposes of a Stakeholder Analysis (SA) may differ greatly between contexts (Allen, 2009). In some cases, the main objectives are to ensure buy-in and predict resistance (Newcombe, 2003; Hovland, 2005). In other contexts, Stakeholder Analyses may be used to provide information on the change context, stakeholder needs, information needs and to increase stakeholder participation. For a problem with several stakeholders, frequent conflicts include long-term versus short-term objectives, cost efficiency versus jobs, quality versus quantity, and control versus independence (Newcombe, 2003). Allen summarizes the different utilities of a Stakeholder Analysis as the potential to:

- Identify and define the characteristics of key stakeholders
- Draw out the interests of stakeholders in relation to the purpose of the project or the problems that the project is seeking to address
- Identify conflicts of interests between stakeholders, to help manage such relationships during the course of the project
- Help identify relationships between stakeholders that may enable 'coalitions' of project sponsorship, ownership and cooperation
- Assess the capacity of different stakeholders and stakeholder groups to participate
- Help assess the appropriate type of participation by different stakeholders, at successive stages of the project cycle, e.g. inform, consult, partnership – all of these have different possible models of communication.

4.1.3.1 Stakeholders in ship design

It has previously been noted that the maritime industry involves a vast and complex network of stakeholders (Lützhöft et al, 2011). Lützhöft et al identify several stakeholders surrounding the owner and operator of a ship that are relevant for the topic of maritime HCD, including:

- The crew
- Design firms
- Equipment suppliers
- Repairers
- Brokers
- Suppliers
- Shipyards
- Classification societies
- Flag State
- The IMO
- P&I Clubs

Van der Merwe (2015) stresses the involvement of four stakeholder groups for the purposes of Human Factors integration in shipping; seafarers, naval architects and ship systems designers, authorities and regulatory bodies, and ship owners/operators.

Solesvik (2011) researched the use of ICT systems for ship design and mapped information exchanges between the ship owner, ship broker, hull shipyard, outfitting shipyard, design agent, national and international organizations, regulatory bodies, classification society, suppliers and the model basin facility.

Gernez et al (2018) point out the difficulties of sharing information between stakeholder groups involved in ship design, for example between designers (ship designer, sub-contractors, shipyard) and the end-users (ship owner, operator and crew). There is often a clear gap between the technical expertise of the designers and the experience of operations, something that can lead to ineffective or unsafe ship design solutions. Despite this, the authors point out, ship design research rarely mentions the selection and engagement of stakeholders that is needed for design process activities. In reality, as pointed out by Agis et al (2019), ship design is a process where stakeholders can represent vastly different interests, and where conflicts and trade-offs may easily result in designs that satisfy certain individual needs while failing to satisfy overall operational goals.

4.1.4 Representation of user needs in design

The process of designing and constructing a ship is complicated and involves many stakeholders, such as owners, operators, crews, designers, shipyards, equipment suppliers, classification societies, authorities, P&I clubs and unions (Rumawas & Asbjørnslett, 2014). Throughout the process, these stakeholders pursue different and sometimes conflicting interests, leading to difficult tradeoffs. Owners/operators want an easily maintainable and operable ship which is inexpensive and safe, cargo owners want their cargo to reach the destination safely, passengers want a comfortable, safe and perhaps exiting trip, the master and crew wants a ship that is easy to operate, comfortable and safe to work at, while the greater society wants safe and environmentally friendly ships (Rasmussen, 2005).

Previous research suggests that typical ship design processes are centered on the ship as a technological object, and do not explicitly factor in the needs of different user groups (Gernez et al, 2018). Ship design is sometimes described as a conservative process that has inherited many of its core principles from olden day shipping (Meck et al, 2009). In a review made by Ulstein and Brett (2012) it was shown that out of 29 different ship design process variants, more than half did not start by capturing the needs of the customer. Costa (2016) notes that, despite efforts made within the IMO to address human element issues, the practice of human-centered design in the maritime domain remains limited. Design work adheres strictly to regulation, and since there are few demands concerning issues such as Human Factors and usability of the ship, user aspects of design are often given a lower priority (de Vries & Bligård, 2019). Much knowledge has already been developed around practical implementations of maritime use-centered design, but this information is not widely known amongst designers or ship/equipment buyers (van der Merwe, 2015). In the words of Rumawas (2016), there is abundant knowledge to be utilized by any designer who wants to integrate user needs into design, but on the other hand, there is no document preventing that such needs are disregarded. In most cases, the stakeholders involved in design and construction are not used to human-centered design practices and may not consider them in the scope of their project (Gernez, 2019:1). As a result, crew knowledge about operations and design requirements will often not be taken into account (Ahola et al, 2018).

Gernez (2018) states that, because the design process involves numerous and complex interactions between stakeholders, there is a need to facilitate these interactions. In a recent paper, Costa (2018) makes a review of previous research that has pointed to potential barriers to use-centered practices in ship design. These include difficulties in defining a user population, fears that user involvement will occupy too much time and resources, lack of consensus around user needs among stakeholders, user difficulties in communicating their needs and a lack of structures for integrating user input into design, difficulties in making tradeoffs between the needs of different user groups, reluctance amongst users to participate, or practical, work-related barriers.

4.1.4.1 Previous studies of the ship design process

A number of previous studies of ship design processes can be found in the literature. These examples may serve as a base for Task T07.2 process investigations. Solesvik (2011) makes a thorough account of a typical ship design process, involving the cooperation both between organization (e.g. shipping company, shipyard, naval architects, classification society, suppliers) and within organizations (e.g. between divisions or branches or subcontractors). Similarly, Gernez (2014) provides a design process overview with the aim to identify important stakeholder interactions. In the following process outline, information from both sources has been brought together:

1. Based on market analyses, the future shipowner sees the need of a ship and develops basic technical design requirements based e.g. on route, ports, geography, cargo type and flexibility (for example, if the ship should be able to work in several markets). The shipowner can choose to build a sister vessel to an existing ship, to introduce minor changes, to order a new similar design or to introduce a fundamentally novel design.
2. The shipping company announces a tender for making project documentation. This is answered by naval architects who prepare an outline specification, a general arrangement plan with three views (GA), a quotation for classification and a rough delivery schedule.
3. The shipping company sends the preliminary specification and GA to shipyards in order to get a rough estimate for construction.
4. The shipping company chooses a design agent and negotiates a contract to produce the design. This involves a tradeoff between what the shipping company wants and needs and what the preliminary budget allows. Some shipyards have in-house naval architect companies and can offer both design and production, which may save some coordination costs.
5. The shipping company chooses a classification society (CS) which reviews classification drawings for regulatory compliance and later makes quality controls during the process of shipbuilding.
6. Detailed drawings are made either by the design firm or by a design agent, the shipyard’s naval architects or by a third-party designer. This decision is usually made by the shipyard which also has this responsibility. Design can follow one of many different methods, for example the “design spiral”, Systems Engineering or Formal Design Optimization.
7. The shipping company together with consultants and shipyard engineers negotiate with suppliers of materials and equipment. A list of equipment and dimensions are used as input for naval architects. Because the selection of suppliers may take a long time, iterative design will often be ongoing during this process.
8. The final price is determined when the yard has a complete specification and materials list from the designer
9. A comprehensive design specification is created, although a great deal of detailed design may remain.
10. “Design for construction” means creating designs that can also be realized technically, or in the selected shipyard. Workshop drawings also take the characteristics of the shipyard into account (e.g. lifting or machine capabilities), which means that workshop drawings for sister vessels produced on different yards may differ.
11. The ship is built at the shipyard. Experience shows that one detailed design specification can still produce several different designs, which means that shipping company, designer, supplier and shipyard interactions are still intense during this phase.

4.1.4.2 Variability & tradeoffs

Gernez (2019:2) and Solesvik (2011) bring up several factors within the ship design process that may affect user involvement and user-centered design solutions.

Firstly, it may often be difficult to tie usability in design to commercial advantages, and because of that, design drivers with more apparent impact on profitability take precedence. In the first stages of a project, designers must also make decisions that shape the continuation of the project, but at this early stage they may be working under tight financial constraints, limiting the possibilities of operational investigations. One way of keeping costs down is to implement off-the-shelf systems, something that imposes a limit to system integration and overall design harmony (Gernez, 2019:2). A similar situation may occur during construction. Since the shipyard does not get paid until delivery, difficult design tradeoffs may result (Gernez, 2018).

No matter the detailing of design specifications, many decisions around design are made during construction, where designers may have little control. These are design changes that may still have significant impact on the end-users. Further increasing the need for coordination in the design process, Solesvik states that it is rather common in Europe for hulls and outfitting to be carried out at different shipyards.

4.1.4.3 Existing frameworks for HCD in shipping

As mentioned previously, there are several existing examples of HCD research and guidance for ship design, e.g. holistic design models, studies on general arrangements and workspaces (e.g. engine room), the ship’s bridge and navigation technology (Costa, 2018).

Lloyd’s Register (2014) offers a comprehensive framework for HCD integration in ship design. A series of publications have been made covering HCD process integration, design knowledge resources and guidance directed specifically towards ship designers and equipment manufacturers.

The CyClaDes framework was developed to assist designers, procurers and shipyards with guidelines, tools and methods for Crew-Centered Design (CCD). The framework takes the form of an online tool following a shipyard contracting structure, where CCD support is offered for contractible design pieces (van der Merwe, 2015).

As part of his dissertation, Gernez (2019) developed the OPAR Framework. The purpose of the framework is to include operative needs into ship design, and to provide methods and artefacts to create a common understanding between designers and operators. Gernez puts a lot of emphasis on field studies and their role in providing designers with an understanding of actual work practices and onboard conditions, as a basis for design. Gernez (2019:2) also comments on the practice of including captains in the design team and using their experiences as the main input to designers. The captain might not know what information to share, and designers might not know what they can obtain from the captain, or indeed how to ask for it.

Costa, in her 2018 dissertation (Costa, 2018), made similar observations. Costa conducted a survey among ship crews in order to identify success factors for end-user participation in design projects. The most prominent of these factors were:

- establishing contact between designers and the “right users”
- eliciting input from the operators of specific ship types for whom the design is directed
- The education and level of experience of the maritime operators participating in design processes was also perceived to influence their perspective on technology, hence age was suggested to be an important user characteristic to consider.
- seeking balance between the users’ requirements and the ship owners’ requirements during design decision-making, as they may not be the same.

- users should be involved beyond the design of systems and workspaces – in rule making and purchasing of new systems and equipment to further opinionate on what should be more suitable for the actual work onboard.

4.1.4.4 The need for a holistic design approach

Several of the authors previously cited argue for holistic approaches to ship design, where designs are adapted to the way crew activities play out in their natural environment. One aspect of holism is that Human-Centered Design should be applied to all kinds of work onboard, not only operations but also cleaning, services, maintenance, and emergency preparedness appliances (Österman, 2013). Another aspect was emphasized in the SEBRA project (Bram et al, 2019), with particular regard to fire safety. In this report, fire preparedness and management is described as a holistic process that not only involves fire-specific roles, tasks, environments and equipment, but where a much broader range of environments, equipment, knowledge and people onboard is relevant. Furthermore, fire safety also connects to many other everyday tasks (such as cargo planning and maintenance work).

This understanding of safety borders on a discussion by Don Norman (2005). Norman criticizes implementations of Human-Centered Design where much attention is given to usability aspects of individual design artefacts, but where too little attention is given to the activities that those artefacts should support. According to Norman, forgetting about the activity can result in system designs that receive good feedback for usability, but that do not adequately support the operational workflow.

4.2 Operational Fire Safety and the Regulatory process

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Fire safety depends on regulations, including regulations that support human centred design (HCD). Bridge equipment designed with usability and ergonomics in mind is most efficient in operations, especially emergencies such as a fire (Bram, Millgård, & Degerman, 2019). Previous research recommends improving fire system design and integration. However, ship design adheres very closely to regulatory demands, and human centred design is not mandatory. As a consequence, little attention is being paid to the design at vessels today (Bram et al, 2019). Thus, the only equipment design that will contribute to fire safety, is the one that actually will be implemented at the vessels because it is practical and comply with regulations (Bram et al, 2019).

This Section discusses the international regulation and regulatory processes that influence design relevant for fire safety on internationally operating ro-ro vessels. Some of the relevant regulations here are IMO regulations about of vessel safety (the SOLAS convention), fire safety systems (the FSS Code), safety management (the ISM Code), and personnel competence (the STCW convention), in addition to a range of industry standards and guidelines.

4.2.1 Regulation

Regulation is “potentially one of the most important defenses against organizational accidents” (Reason, 1997, p. 182). It is in essence about decreasing the companies’ discretionary space in order to protect employees, customers, and society, among other stakeholders (Grote & Weichbrodt, 2013). The public do not trust market forces to always choose the safest alternative (Johnson, 2014), so pressure through regulation is preferred. Baldwin, Cave, and Lodge (2011) describe three different, but overlapping types of regulation:

1. A set of requirements enforced by a regulatory or supervisory authority
2. A deliberate state influence aimed at influencing organizations and individuals
3. All forms of social influence exerted over the behavior of the regulated actors, not only from states, but also from market mechanisms, for example.

In this report, the term regulation refers to the formal set of rules or conventions made by governments or international policymakers and the communication between regulatory agencies and actors involved in the shipping industry.

Two basic types of regulations are functional/goal-based and prescriptive/specified rules, and the functional rules are increasingly common. The rules in for example safety management regulation (the ISM Code in SOLAS) are functional: They focus on a goal that the companies themselves know how to achieve (Reason, 1997). Instead of prescribing detailed rules, regulators lay out functions that companies should incorporate into an auditable system (Lindøe, Baram, & Renn, 2013). Such safety rules allow "considerable freedom on the part of the operators of hazardous technologies to identify the means by which these ends will be achieved" (Reason, 2013, p. 175). This makes the procedures more sensitive to variations and easier to change while reducing public costs (Lappalainen, 2017, p. 10). See Lindøe et al. (2013) for discussions about problems and benefits of prescriptive and functional rule sets.

Functional regulation leads to so-called "co-regulation," because it demands cooperation between the companies and the reviewing institutions (Baram & Lindøe, 2013, p. 22). This review can come under the name of control, audit, supervision, inspection, and vetting, and are performed by both national authorities and other regulatory actors. Contributing to fire safety on ro-ro vessels, there are several relevant regulatory actors that influence and develop policies and regulations.

4.2.2 Regulatory actors

The best approaches to achieve safety are continuously transformed in meetings between regulators, companies, and employees (Gherardi & Nicolini, 2000; Latour, 1987). Previous research pictures how international maritime regulation is created in a network of actors involving governmental agencies, shipping companies, standardization organizations, classification societies, system suppliers, auditors, and inspectors (cf. Størkersen, 2018). These actors pursue partly different goals, and they have different ways of influencing the regulatory process. Fundamental for regulations and enforcement are IMO, Paris MoU, the recognized organizations, national states, EU and standardization organizations.

4.2.2.1 The International Maritime Organization (IMO)

The IMO is the United Nations' specialized agency responsible for the safety and security of shipping and the prevention of marine pollution by ships. The IMO is a global standard-setting authority that seeks to create a fair, effective, and universal regulatory framework "so that ship operators cannot address their financial issues by simply cutting corners and compromising on safety, security and environmental performance" (IMO, 2017b). The IMO was founded in 1958, before which several international conventions had been developed, including the International Convention for the Safety of Life at Sea (SOLAS, 1914). When the IMO was established, it incorporated conventions like SOLAS. The IMO now has 171 member states and 3 associate members, in addition to the 64 intergovernmental organizations and 76 international non-governmental organizations that have consultative status to ensure information sharing and coordination in relevant matters. The IMO conventions are formulated in agreement by all participating members. They come into force through consensus by all 171 member states, but since the early 1970's a "tacit acceptance" procedure has ensured that a given state does not have to accept a convention explicitly; rather, it must object before a certain date if it is opposed to the convention. Generally, the regulations enter into force 18–24 months after formulation negotiations have finished.

In addition, specialized committees address certain topics continuously. The discussions and work in these committees can result in recommendations from IMO. For example, fire protection and lifesaving appliances are dealt with by the subcommittee on Ship Systems and Equipment (SSE), reporting to the Maritime Safety Committee (IMO, 2020). Training is addressed into the HTW (Human Element, Training and Watchkeeping) subcommittee. On the latest HTW, in 2020, revisions of «Advanced training in firefighting», «Bridge resource management» and «Engine-room resource management» trainings were discussed.

An IMO report states:

> *IMO's regulatory work is a comprehensive body of international conventions, supported by literally hundreds of guidelines and recommendations that, between them, govern just about every facet of the shipping industry…. To a considerable extent, this success story of shipping in terms of its improving safety and environmental record can be attributed to the comprehensive framework of rules, regulations and standards developed over many years by IMO, through international collaboration among its Members and with full industry participation. (IMO, 2012, p. 43)*

The IMO has no power to enforce conventions, except in vetting of certain training and examination. Other enforcement is formally up to the national states that ratify the IMO regulations, which in many cases further delegate the authority to recognized organizations.

4.2.2.2 Memorandums of understanding

Across the globe, there are nine regional agreements of port state control, and these agreements has central roles in the enforcement of transnational regulation. The Paris Memorandum of Understanding is an organization of 27 maritime administrations in Canada and Europe (including Russia) that seeks to eliminate "sub-standard ships through a harmonized system of port State control" (Paris MoU, 2017). The Paris MoU organization also trains and authorizes officers who monitor ships in European and Canadian ports in port state controls and determines the exact nature of compliance with international conventions.

4.2.2.3 The EU

The European Union (EU) is increasingly important for international maritime safety policymaking because it can enact regulations that are directly binding on all member states (Norwegian Standing Committee on Business and Industry, 2006-2007). The EU is an economic and political partnership between 28 European countries. All actions taken by the EU are founded on treaties that are negotiated, agreed to, and ratified by all EU member states (EU, 2013). The EEA countries (Iceland, Liechtenstein, and Norway) contribute to the formation of new, relevant regulations at an early stage, but have no representation in or formal opportunity to influence further decision making within the EU, although they are obliged to ratify EU conventions (EFTA, 2017). Much work related to fire safety is performed in the EU's maritime safety agency (EMSA). EMSA only gives advice to the European Commission, which is the body that establishes regulations.

4.2.2.4 National authorities

The national maritime authorities' "activities are governed by national and international regulation, agreements and political decisions" (Maritime Authority, 2017). Example of tasks for a national maritime authority are to serve as an adviser that provides guidance to their customers and government, be a driving force for safety, act as a supervisory authority through certification and control of vessels, and participate in the development of national and international regulations (Maritime Authority, 2017).

The state owning a vessel is responsible to control that the ship owner maintains the safety of seafarers, material values, and the environment. Flag state controls of vessels are executed by the authority of the country where the vessel is registered (flagged). Some auditing of ISM, hull, machinery, load line, and vessels under construction are delegated to recognized organizations (see next section). During an audit, the inspector notes deviations from the regulations to which the ship owner must attend before obtaining a certificate or passing the inspection. If the ship owner fails to meet all requirements by a deadline, the maritime authority can levy day fines or restrict the vessel in port. Foreign-registered vessels must also comply with the regulations of the waters they are operating in. These vessels are expected to be supervised and inspected by their flag state.

The national authority inspects foreign vessels in Norwegian ports based on international port state control regulations (Paris MoU, 2015a). The port state controls the vessels' Maritime Labour Certificates and Declaration of Maritime Labour Compliance (IMO, 2017c; Maritime Labour Convention, 2013; Paris MoU, 2015a). The comprehensiveness and frequency of inspections depend on a vessel's flag and history. Usually, they only briefly cover seafarers' contracts and physical working environment, with working conditions and daily life on board largely ignored (Sampson, Walters, James, & Wadsworth, 2014; Silos, Piniella, Monedero, & Walliser, 2012). Possible sanctions are detention and exclusion of the vessels, but this is onerous for inspectors and not favourable for trade relations, so such acts are kept to a minimum. It is common for vessels to be cited for at least some deficiencies during each inspection (Soma, 2004).

4.2.2.5 Recognized organizations

Ship owners, vessels, and seafarers need to be classified and certified that they comply with IMO conventions and national regulations. Much of this is delegated to private recognized organizations (IMO, 2017a). They are given the authority to inspect vessels. The recognized organizations carry out inspections according to national regulations (often specified by class requirements, which have been developed to ensure that inspection and certification are standardized). The recognized organizations determine ship owners' rule compliance based on regulations assembled in the RO Code (RO Code, 2013).

Several organizations have such authority, and ship owners can contract for this service from any authorized organization. Recognized organizations are also called classification societies or consultancies. Well-known large classification societies include DNV GL, Lloyd's Register, Bureau Veritas, and the American Bureau of Shipping, but there are also one-person companies who deal with some regulations. The largest classification societies are members of The International Association of Classification Societies (IACS) and develops requirements and guidelines so recognized organizations have common standards in their interpretation of governmental regulations. Yet, recognized organizations assess certain aspects differently, so ship owners are known to prefer organizations that go easy on their weaknesses (Silos, Piniella, Monedero, & Walliser, 2013). In an effort to standardize recognized organizations, their performance is ranked internationally (Paris MoU, 2015b), and the flag states audit them and participate in some revisions (Norwegian Ministry of Trade Industry and Fisheries, 2016).

4.2.2.6 Standardization organisations

It exists a line of global and national organizations developing standards connected to or based on the international and national regulations. On the field of fire safety, the International Electrotechnical Commission (IEC) is particularly influential. IEC develops international standards for electric and electronic products, systems and services, specifying public regulation and IMO regulations.

4.2.3 Maritime regulation contributing to fire safety

International maritime agreements have been championed since the nineteenth century. In early times, whether a ship was safe depended on its seaworthiness and its crew's seafaring skill, but this was difficult to control with any uniformity (Soma, 2004). In 1914, following the loss of Titanic, the first Convention for the Safety of Life at Sea (SOLAS) was agreed upon internationally. Early regulation covered many aspects related to safety, such as technical qualities of cargo, the vessels themselves, ship owners, market and contract relationships, insurance, and personnel certificates. "From focusing on the technical and regulative subjects, the trend the latest 25 years have been to address the company behind the ships. It has been common to state that behind any Sub-Standard ship there is a Sub-Standard owner or manager" (Soma, 2004, p. 13). Sub-standard means that a ship's vital parts or lifesaving equipment are substantially below the standards of national or international regulation.

Most regulations related to fire safety on ro-ro vessels are connected to SOLAS and the IMO (which is further ratified and enforced by the national states, as well as translated or specified by standardization organizations and certifications). Below, some aspects of some regulations are described and commented as examples relevant for fire safety. For further reviews of regulations, please see IMO (2020), Leroux and Mindykowski (2017), and internal reports in the LASH FIRE project.

4.2.3.1 Technical safety and design

Technical safety of the fire systems is regulated by the SOLAS convention, including the FSS Code. This is also covered by classification standards (such as IACS' unified recommendations) and global standards (such as IEC). For example, IACS UR E22 reckons the fire detection system as a category III, i.e. in case of fire, its failure could "immediately lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment". It therefore sets a number of requirements for the system supporting software development and testing process, aiming at ensuring its operational reliability. A number of these technical regulations related to alarm management are relevant for integration in the fire alarm system interface.

While the technical design is well accounted for in regulations, the functionality and design of interfaces is mentioned in one IMO recommendation: MSC.1/Circ.1615 gives a few brief directions on usability and ergonomic goals that should be pursued in fire alarm system design. Usability efforts on ships mainly extend to operational bridge functions such as navigation and manoeuvring (e.g. MSC/Circ.982).

One EU directive that clearly affects fire-safe design, is the Marine Equipment Directive (MED). MED is a certification mandatory for all equipment installed on EU/EEA vessels. Certification can be approved by class/consultant companies.

4.2.3.2 Competence and safety in operations and during emergencies

The use of the technical system and design also depends on the competence and procedures of the personnel.

Competence and training requirements for personnel are primarily covered by the STCW convention. For example, minimum levels for training and competence are defined in the KUP (knowledge, understanding and proficiency) table A-VI/3 of STCW – in the Advanced Firefighting Course tasks are to control firefighting operations aboard ships, organize and train fire parties, inspect and maintain fire detection and fire extinguishing systems and equipment, and investigate and compile reports on incidents involving fires. Many vessels also adhere to other requirements/guidelines about operations and training – like international standards such as ISO, NFPA, or national regulations (e.g. labour laws). Some general operational and training aspects are required by SOLAS. For example, SOLAS II-2 Reg. 15: «Crew members shall be trained to be familiar with the arrangements of the ship as well as the location and operations of any fire-fighting systems and appliances that they may be called upon to use».

Operations of the fire safety equipment is commonly not described in procedures, but in the user manual of each manufacturer.

Running daily operations and training for emergencies, however, are covered by SOLAS in its chapter about the International Safety Management (ISM) Code. The ISM Code is a functional rule set that instructs companies to establish a system that can be inspected both internally and externally through audits. The main objectives are ensuring "safety at sea, prevention of human injury or loss of life, and avoidance of damage to the environment" (IMO, 2017c). It states that ship owners' objective should be to provide systems for safe practices, risk assessments, and safeguards, and to "continuously improve safety management skills of personnel ashore and aboard ships." (the ISM Code's objectives, § 1.2.2). This is usually manifested in procedures for specific activities that the personnel should carry out, how to perform them and, in many cases like maintenance, how often to do them. Also, the ISM Code § 8 is about emergency preparedness, and requires the companies to identify potential emergency situations, establish procedures, programmes for drills and exercises, and measures to respond to hazards and emergencies. In practice, other regulations are also included in a safety management system, often involving industrial standards or customer requirements, but emergency procedures are usually straight forward.

4.3 Human Factors and Human-Centred Design in the maritime sector

In addition to the findings from Firesafe II (Leroux, 2018), SEBRA (Bram, Millgård, & Degerman, 2019) and the LASH FIRE internal report IR05.8 described in chapter 3.3, this section is a short review of regulations, guidelines and research literature addressing HF/HCD in ship bridge design.

4.3.1 Regulations and guidelines addressing HF for ship bridge design

There is a gap between rules and requirements for user-centred design of an alert management system and what is experienced by navigators in practice (Merwe, 2016).

SOLAS Regulation V/15 Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures reflects the importance of human-centred design:

All decisions which are made for the purpose of applying the requirements of regulations 19, 22, 24, 25, 27 and 28 and which affect bridge design, the design and arrangement of navigational systems and equipment on the bridge and bridge procedures shall be taken with the aim of:

.1 facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions;

.2 promoting effective and safe bridge resource management;

.3 enabling the bridge team and the pilot to have convenient and continuous access to essential information which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays;

.4 indicating the operational status of automated functions and integrated components, systems and/or sub-systems;

.5 allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot;

.6 preventing or minimizing excessive or unnecessary work and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot; and

.7 minimizing the risk of human error and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action.

The IMO also provide guidelines in the form of circulars:

- MSC/Circ.982. IMO Guidelines on ergonomic criteria for bridge equipment and layout.
- SN.1/Circ.265. IMO Guidelines on the application of SOLAS Regulation V/15 to INS, IBS and bridge design.
- MSC.1/Circ.1512 Guideline on software quality assurance and human-centred design for e-navigation.

As pointed out in previous research, these efforts mainly extend to operational bridge functions such as navigation and manoeuvring (e.g. MSC/Circ.982), while fire management onboard relies on functions distributed across the ships, involving many different systems and working environments (Bram et al, 2019).

In addition, it’s worth mentioning existing ISO standards for HCD in general and for ship bridge layout:

- ISO 9241-210:2010 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems
- ISO 9241-220:2019 Ergonomics of human-system interaction — Part 220: Processes for enabling, executing and assessing human-centred design within organizations
- ISO 8468:2007 - Ships and marine technology -- Ship's bridge layout and associated equipment -- Requirements and guidelines. 2007.

4.3.2 HF/HCD literature for ship bridge design in general

Over the last decades there has been a steady increase in digitalized products, applications and services introduced to the maritime domain. This development has been rapid, illustrated by the number of items of equipment at the main workstation increased from 22 to 40 during the period of 1990 to 2006 (Lützhöft, Sherwood Jones, Earthy, & Bergquist, 2006). These sophisticated IT-based systems are being introduced on ships (often as a regulatory requirement) without taking account of the abilities, knowledge and skills of the crew and shore staff to use this equipment. As a result, workload has not been reduced as intended, but rather shifted to another form described by Lützhöft (2008) as integration work. Integration work exists on several levels and includes integrating human and machine work, as well as information representations (Lützhöft & Nyce, 2008). The human factors issues are pertaining partly because the maritime industry has recognized the importance of human factors later than other safety-critical industries like aviation and nuclear (Lützhöft, Grech, & Porathe, 2011).

Bridge layout and design has been found to directly impact team work, hence Sørensen, Lützhöft, and Earthy (2018) argues that a requirement for minimum manning for the bridge that is linked to bridge layout should exist. Although the number of staff and their competence may be adequate according to STCW, company procedures and industry best practice standards, the bridge layout and design may hamper teamwork at different levels according to the operational mode (ocean, coastal watch, arrival, departure, and pilot on board).

Research on ship bridge design has covered factors influencing the success of human-centred design in the shipping industry, discussing how several stakeholders, their collaboration and human factor knowledge is crucial (Gernez, Nordby, & Sevaldson, 2014; Mallam, Lundh, & MacKinnon, 2017). Authors have developed guidelines (Grech & Lutzhoft, 2016) and design frameworks (Antão, Teixeira, & Soares, 2013) aimed at improving the human factors integration into the design process.

Some research has focused on how engineering can better utilize human factors knowledge. The lack of a systematic, industrial application of human factors in the maritime domain has been linked to the epistemologically determined working differences between human factors and engineering (Petersen & Lützhöft, 2009; Petersen, Dittmann, & Lutzhoft, 2011; Petersen, Nyce, & Lützhöft, 2012). It is argued that the differences between these disciplines should to be understood and “Engineering needs to appreciate that the relevant social sciences are more than common sense, while Human Factors scientists must learn to appreciate the heuristic nature of Engineering” (Petersen et al., 2011). To improve maritime designers’ knowledge about human factors, human-centred design and ship operations a framework for transferring HF/HCD knowledge to maritime design engineering students’ education in a more targeted, engineering-oriented fashion has been developed (Abeysiriwardhane, Lützhöft, Petersen, & Enshaei, 2016).

Other research has focused on the designers and their knowledge about the field they are designing for. An interview study with designers from different nautical developmental units involved in ship bridge design revealed that designers had a general interest in in usability, interaction design and human factors, however there was a lack of detailed, concrete knowledge and they had very different notions on topics such as basics of ergonomic design, human factors and usability, feedback loops in design, and system knowledge of the user (Meck, Strohschneider, & Brüggemann, 2009).

Field research to inform design in the maritime industries has rarely been performed, although according to Lurås and Nordby (2015) field research is paramount for designers to develop *designers’ sea sense*. Sea sense is connected to sensemaking and involves gaining a detailed knowledge about the environment they design for as well as an embodied understanding of what it is like to be a seafarer. Field research includes experiencing and observing life at sea as well as contact with end-users which may be hard to reach on shore. A guide for design-driven field research has been developed as practical advice available for designer taking on marine design projects (Lurås & Nordby, 2014; Lurås & Nordby, 2015; Nordby et al., 2019). Training courses for designers to be able to utilize field studies has been proposed (Nordby et al., 2019). It has also been pointed out that usability studies in simulated or real environments with the end-user can reveal the gap between designers and end-user (Man, Lützhöft, Costa, Lundh, & MacKinnon, 2017). An example of this was a design effort to develop direct gesture interaction for DP vessels. Tests with end-users showed that traditional touch-screen button and menu interaction was quicker and less erroneous than gestures, and the difference was accentuated by the moving environment (Bjørneseth et al., 2012).

By using vessel designs as a mediating tool between designers, users and human factors specialists, as well as basic task analysis and link analysis methods, (de Vries, Hogström, Costa, & Mallam, 2017) showed that a human-centred approach may successfully be achieved within the context of ship design. They claimed that the human-centred approach had improved ship safety, as well as safety, efficiency and cost-effectiveness in operations.

Other efforts to further develop the ship bridge design to accommodate user needs has been suggesting that the bridge equipment should be adaptive. It should be able to adapt to the user's situation-dependent and task-based information need by giving supportive advice and thereby reducing the crews work in finding, sorting, processing and integrating information (Denker, 2014). Another approach is to base the bridge layout on operator workload and stress levels by having support for different control levels in different locations on the bridge (Porathe, Hoem, Rødseth, Fjørtoft, & Johnsen, 2018).

Eye tracking data in human-computer interaction is a valuable tool to identify challenges with design and user interfaces, and to better understand the workload of the subject. Hareide, Mjelde, Glomsvoll, and Ostnes (2017) used eye tracking data to identify user requirements which in combination with a human-centred design process led to the development of an improved software application on essential navigation equipment.

An approach to develop usable navigational displays, is to logically group data and control functions to allow the bridge team convenient and continuous access to essential information. A user-led grouping of navigation data identified a grouping pattern of twelve information groups. The groups indicated a task-orientation in addition to artefact-related (e.g. own ship, target)(Vu & Lützhöft, 2018). Another approach is functional allocation, (Hogenboom, Rokseth, Vinnem, & Utne, 2020) provide recommendations regarding function allocation of control and visualization of operational risk to enhance operator performance and reliability in DP operations.

User-centred design has been criticized for not providing new possibilities and new types of design solutions (Wahlström, Karvonen, Kaasinen, & Mannonen, 2016). The solutions correspond to closely to the existing models of activity and the involved users are often not aware of forthcoming technical opportunities. Wahlström et al. (2016) propose a design approach for radical concept design for a ship bridge design case. It combines the user-centred design approach with foresight of technology trends and future developments.

4.3.3 Ship bridge alarm system design research

There are numerous publications on alarm system design to be found from other sectors, like process plants/industry control rooms and not so much published specifically concerning alarms on ship bridges.

The number of alarms on a ships bridge has been increasing over the last decades as the number of systems onboard capable of generating alarm has increased and the number of alarms associated with each system has increased (Jones, Earthy, & Gould, 2006). Alarms are generated by external sources like GMDSS and AIS as well as internal sources, including non-critical Commercial Off the Shelf devices generating sound.

Alarm management influences safety and common areas of concern among seafarers include distraction from nuisance alarms, excessive workload accepting multiple alarms caused by a single incident, alarm messages that are confusing or unclear, difficulties in differentiating and locating audible alarm signals lack of indication of priority of alarms (Jones et al., 2006; Motz & Baldauf, 2007; Onarheim, 2017; Vu, Lützhöft, & Emad, 2019). The inappropriate use of alarms to convey non-critical information to the operator contribute to change the role of operator to a more passive “driving to alarms” role instead of being actively in control (Jones et al., 2006). The fire alarm management is performed within this reality and to function as well as possible the overall alarm management on the bridge is crucial.

Experiments have shown that introducing heterogeneity into an alarm set makes it easier to learn and remember (Edworthy, Hellier, Titchener, Naweed, & Roels, 2011). Also, tactile cues have been shown to have shorter response time compared to vibro-tactile, visual and auditory cues. Tactile in combination with other cues such as visual and auditory can enhance the effectiveness of response time and should be explored by maritime designers (Pan, Renganayagalu, & Komandur, 2013). Strazdins, Komandur, and Bjørneseth (2014) argue that tactile cues can be more efficient than audible cues in directing operator attention to the desired location as well as indicate the type and source of alert. They are developing a tactile belt for the operator to wear during daily activities. The tactile cues are generated by vibrating motors situated across the abdominal region of the user.

A joint industry project with the objective to improve “the human-centred design of alert management systems on the bridge so that it supports navigator performance” developed a design guideline for alert management systems on the bridge (Merwe, 2016). The guideline illustrates the potential for improving the alert management system within the margins of applicable rules and regulations. The guideline contains general considerations for alert system management that may be useful regardless of whether the vessel Bridge Alert Management (BAM) installed, although its focus is mainly on navigation.

The key principles that the developed guideline is based on:

- Alerts should direct the navigator’s attention toward vessel conditions requiring timely assessment or action,
- Alerts should inform and guide required navigator action,
- Every alert should be useful and relevant to the navigator, and have a defined response,
- Alert levels should be set such that the navigators have sufficient time to carry out their defined response before the situation escalates,
- The alert system is to accommodate human capabilities and limitations.

A traditional view of the alert management system has been as a system for logging all significant system events, however that kind of information is most useful for an engineer. A user-centred alert management system should present what is most relevant to the operator. In general Merwe (2016) states that collaboration and improved communications between stakeholders; system manufacturers/bridge integrators, equipment manufacturer/sub-contractors, yards and ship-owners is the way forward. The report suggests three measures:

- Redefining the roles and responsibilities of the stakeholders involved in alert management system design, the responsibility for designing the alert management system is scattered and suggest that the system-integrator should be the “spider in the web” – key stakeholder to take responsibility human centred design
- Reduce the number of alerts that reach the bridge, bottom up approach where it should be argued why any signal should become an alert. Equipment supplier/manufacturer will need to justify the inclusion of any non-mandatory alerts.
- Improve the presentation of alerts by presenting a checklist to support stakeholders performing the human centred design of alert management system

4.4 State of the art in system interface design

Main authors of the chapter: Torgeir Kolstø Haavik, NSR; Brit-Eli Danielsen, NSR

Unlike in the aviation industry and in aircraft cockpits, information and actuation systems in maritime bridge environments have a very low level of standardization. However, there are indications that this heterogeneity in the maritime industry is being challenged by an increasing number of initiatives aiming for more standardized solutions.

There are examples of successful ship design where end-users and stakeholders have been involved in an iterative design process: the Tamar-class lifeboat, operated by the Royal National Lifeboat Institution (RNLI); the Service Operations Vessel 90 20, designed by Damen Shipyards Group; and the Pure Car/Truck Carrier (PCTC) Harvest Leader, designed by Andreas Shipping Ltd (Lützhöft & Vu, 2018).

The Ulstein Bridge Concept (UBC) research and innovation project developed a conceptual design vision for a future ship bridge based on the design processes and competencies of industrial and interaction design. The concept was first introduced in 2012 and includes work space designs and new ways to interact with bridge systems, e.g. gesture-controlled infographics displayed on bridge windows. The award-winning conceptual design visions have initiated several patents, generated ideas for further product development and fostered a new understanding of how to design for the mariners' work environment on an offshore ship bridge (Kristiansen, 2014).

The Rolls Royce Unified Bridge (RR UB) was developed by Rolls-Royce Marine (now Kongsberg Maritime CM) based on a research and development project where they performed a complete redesign of the ship bridge environment, including consoles, levers and software interfaces (Bjørneseth, 2014). One of the objectives was to achieve consistency across applications concerning the graphical user interface (Bjørneseth, Dunlop, & Hornecker, 2012). The holistic bridge concept was sailing at sea for the first time in 2014. This concept was not as radical as the UBC as it was developed based on existing technology in order to realise a product to the marked.

Another R&D initiative that should be mentioned is The OpenBridge project. It was initiated in 2017 with a purpose to achieve cross-vendor integration and consistent user interfaces for all maritime equipment in a ship´s bridge (Nordby, Gernez, & Mallam, 2019). The project has significant industry collaboration with 27 partners from industry, government and academia. The core deliveries of OpenBridge are a voluntary design guideline and a set of implementation tools that together make up a "design system" that aim to lay out how to design central parts of maritime digital user interfaces. The project will support both user interface design and technology integration. The design guideline is open source and free to use (http://www.openbridge.no).

4.5 Analysis of accident investigations

The Firesafe II project (Leroux et al., 2018) included a review of 24 accidents focusing on the fire detection and the decision to activate the fire-extinguishing system phases of the accidents. As these findings were integrated in the LASH FIRE project planning a review of these reports have not been performed a second time.

Although there is a great potential in learning from accidents, it is not straight forward to draw conclusions from a sample of accident investigation reports. The reports vary in the depth and breadth of information attained and analyzed and they rarely include descriptions of the crew interaction with bridge alarm panels that took place during the course of the accident. It is important to keep in mind that the investigation methods used, and the causes found in an accident investigation report reflect the investigation teams' assumptions of how accidents happen and the factors or causes to look for. This is described as the What-You-Look-For-Is-What-You-Find (WYLFIWYF) principle (Hollnagel, 2008). The main purpose of an accident investigation is to learn how to avoid future accidents and as such it may make sense for investigators to look for specific individual problems that can be fixed. This leads us to the What-You-Find-Is-What-You-Fix principle (Lundberg, Rollenhagen, & Hollnagel, 2009), meaning the limitations in the investigation will limit what kind of improvements can be made.

From the Firesafe II accident investigation report review the following factors concerning design of the fire alarm system and information needed on the bridge were described:

Technical system design

- In most cases it was smoke detectors that detected the fire. Several of the investigation reports emphasize the benefits of having both smoke and heat detectors installed, to be able to detect different fire types.
- In some cases, the fire was detected by the crew on fire patrol or crew passing by the location by chance before any reaction by the technical systems.
- Some of the reports describe technical internal failures with the fire detection systems hampering detection by the crew. In the Commodore Clipper accident the initial alarms were interpreted as technical malfunction (MAIB, 2011).
- In a number of cases fire localization was obstructed due to malfunctions in the fire alarm system or that the alarm system provided misleading or imprecise information. One such case is the Pearl of Scandinavia (DMAIB, 2011) where fire spread, unclear alarm information and obstructed visibility caused an erroneous interpretation of the origin of the fire, creating false grounds for decision-making and delaying response. On the Joseph and Clara Smallwood (TSB, 2005) a watchman was able to localize the fire, but because he received no feedback when pulling the nearest fire alarm switch, the watchman commenced to another location pulling yet another switch, possibly creating confusing around the actual location of the fire.
- CCTV assessment was attempted in most incidents but has primarily offered confirmation of fire (e.g. cameras blocked by smoke).
- On several occasions, poor accessibility has essentially made the fire a black box and decisions have been made mainly based on information about temperature development in different parts of the ship. In these situations, technical artefacts such as heat cameras have been important for situation assessment, although a simple checking with the hand against bulkheads has also allowed crew members to gauge the development of the fire.

Interface between crew on the bridge and crew present at the fire scene

- The early deployment of a runner to the fire scene seems to offer advantages both for speed of assessment and first response. Despite this, situation assessment (e.g. the condition, spread and damage cause by the fire) proved a great challenge in all of the reviewed incidents. Some problems arose from issues in the interface between crew present at the fire scene and decision-makers on the bridge.
- For officers on the bridge, problems with communication can undermine their situation awareness and have negative effects on decision-making. The reviewed incidents provide a number of examples of factors that may inhibit communication. The most common of those factors is malfunctions or reduced functionality in technical communication equipment, such as poor audio quality or insufficient coverage, requiring the coordinating person to move around and thus losing precious time. There are also examples of environmental factors inhibiting communication, such as noise or loud alarm signals.

Stowage and cargo information

- In several cases, situation assessment was heavily influenced by poor accessibility caused by tight stowage and smoke. On several occasions, problems with situation assessment produced delays in decision-making that allowed the fire to develop further.
- There is one mention of cargo documents being used for situation assessment (DMAIB, 2011), although in this instance the documents did not contain all the information about the cargo necessary for assessment.
- In several of the reviewed incidents, fire started in cargo deck environments with very limited access both for confirmation and fire response. Efficient stowage allows cargo capacity to be maximized, but at the same time makes it harder for fire response teams to reach the fire seat carrying heavy and cumbersome equipment, in particular the pressurized hose. In several instances, such as with the Joseph and Clara Smallwood (TSBC, 2005), it was not possible to completely put the fire out until the ship had docked and several vehicles had been removed from the deck. It is also common that both situation assessment and fire response is inhibited by smoke at the deck, despite the use of Breathing Apparatus (BA) equipment.

Drencher activation

- There are several examples of situations where design flaws in environments, interfaces or equipment connected have introduced delays in drencher decision-making and activation. These flaws include insufficient or obstructed section markings provoking a kind of trial-and-error in drencher activation, illogical ship layout drawings in the drencher room that all the components (e.g. pumps) required for drencher activation have not been located in the drencher room and impaired valve operation due to stiffness.
- Drencher activation is often associated with negative side effects that can both delay fire extinguishment and create operational hazards. The primary challenge is to handle the large quantities of water on deck created by the drenchers. Water outlets will often become blocked by debris from the fire. This may force the captain to make trade-off decisions. One such case is the Commodore Clipper (MAIB, 2011) where the drencher had to be run in intervals in order to maintain stability of the ship. In this case, it is noted that the officers lacked a way of calculating how much water could be accumulated without losing stability. There are also examples of creative ways of draining drencher water, for example using the

ballast system to heel the ship allowing the water to escape. On the Al Salaam Boccaccio (PMA, 2006), however, attempts to use the ballast system for this purpose ultimately led to the sinking of the ship.

Ship operation

- Past incidents provide several examples of decisions surrounding ship operations that are made in order to inhibit an ongoing fire. This includes different ways of maneuvering cargo deck fans for different purposes such as removing smoke, avoiding vacuum effects or to inhibit fire growth. Another common example is to alter the ship's course in order to direct smoke away from crew/passenger areas or to enable manual fire response. It is also apparent that some operational scenarios, such as berthing with an ongoing fire onboard, create serious challenges for crew resource management.

5 Method

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Studies that have provided data for D07.1 have all been conducted using a mix of qualitative methods, which are described further in the following sections.

5.1 Literature Review

For the purposes of ship design process studies, literature searches were conducted for the following purposes:

- To find prior examples of research efforts on the ship design and construction system
- To form a methodological base for stakeholder and process analyses

Online databased were searched using combinations of the following keywords*: ship, maritime, stakeholder, process, systems, analysis, socio-technical/sociotechnical, STS, design, production, human-centred/centered design, HCD, usability.*

For the purposes of alarm system interface design, the research and guidelines literature was reviewed for generic and maritime-specific design 'rules' and guidelines. There is an extensive literature on design and usability, and research and guideline literature was selected to match experienced usability concerns with research sources that are known to address these concerns. The research literature referred to is rooted both in 'traditional' human factors design and resilience-oriented design – here also to be denoted theoretical and pragmatic approaches to human factors. The more practically oriented reports and guidelines referred to were selected on the basis of searches with particular search strings that included *alarm panels, maritime, fire, human-centred design* and *human factors*. Reference lists in previous research literature was also used to supplement the literature study.

For the regulatory analysis, similar document studies have been performed. Regulations in themselves; documents and web pages about regulations and regulatory actors, as well as relevant research literature have been analysed to understand what regulations, actors and regulatory processes are important for fire safety and design.

5.2 Interviews

To support stakeholder interviews, an interview guide was developed, based on the outcomes of the literature review and previous research, covering both stakeholder and process topics. This guide was used for semi-structured interviews lasting 1-1,5 hours. A total of 6 shipping company Design

Team/Site Team members belonging to the same organization, 1 class representative, 3 insurance business representatives and 3 design firm representatives were interviewed.

For the alarm system interface design studies, in addition to unstructured conversations with crew members, structured, formal interviews were conducted with four bridge officers with experience and responsibilities in fire situations. Two of the informants were masters and two were chief engineers.

The COVID-19 situation affected interview plans in the spring 2020, resulting in a number of interviews that were lower than initially planned, and were conducted over video instead of face-to-face.

Project information was administered before interviews and consent was sought using a consent form, although consent was given verbally at the time of the interview. Interviews were recorded and transcribed in verbatim. Thereafter, they were subject to coding. The coding was framed to communicate with theoretical frameworks and literature findings presented in the Background chapter.

5.3 Accident analyses review

This report builds on the work of previous studies such as the Firesafe II and the SEBRA study. The findings from accident reports that were made within these studies were integrated in LASH FIRE project planning, and are therefore implicitly part of the methodical apparatus of this work. In addition, results from previous studies have been scrutinized again in order to identify findings that may have a particular bearing on WP07 research activities.

5.4 Participant observation and discussions in operative environments (onboard ships)

Facilitated ship visits and unstructured discussions with the crew was an important method for individual researcher familiarization, development of common ground, and contextual empirical investigations. The researcher team conducted four such dedicated visits to berthed ships. Typically, the visits lasted for 3-4 hours, and included general tours, sometimes observation of fire rehearsals, and unstructured, but thematically focused conversations with crew members. Crew members sometimes came and went during these excursions, but altogether the number of crewmembers that took part in these discussions were between fifteen and twenty.

In addition, members of the research team participated on a 24h roundtrip with a Ro-pax ship, with opportunities given to substantial discussions with the crew over long time, under shifting circumstances.

5.5 Stakeholder Analysis

Lelea et al (2014) describe a Stakeholder Analysis procedure in five steps:

1. Define the human activity system the research focuses on,
2. I*dentify* the actors who make up this system, and characterize their roles and relationships,
    a. Identify Actors, Agendas, Arenas, Alliances
    b. Investigate power, resources and relationships, as well as issues of social difference
    c. Identify ‘primary’ and ‘secondary’ stakeholders
3. Formulate the specific issue or problem to address,

4. A*nalyze* which of these actors are related to the specific problem or issue that is the focus of the research project,
5. S*election* of whom to include as participants in the research.

Berlin et al (2017) present another method for Stakeholder Analysis named CHAI (Change Agent Infrastructure), directed towards ergonomics- and work environment-related change projects. This method involves a seven-step process including stakeholder identification, problem formulation, problem relations, a hierarchical organizational sorting and an analysis of power bases. Since Human Factors- or ergonomics changes may often be associated with resistance and conflicts, this method emphasizes the roles that stakeholders play in the process, either as Initiators, Sponsors, Subjects, Change owners, Solution builders, Documenters, Blockers and Convincers.

It has previously been noted that Stakeholder Analysis stems from the field of Management Research, which is reflected in common Stakeholder Analysis practices (Berlin, 2017). For example, a common element of a stakeholder analysis is to categorize stakeholders according to their predictability and power base, aiming to manage risk (and resistance) in a change process. Stakeholders with little power may be described as “easily manageable” (Newcombe, 2003) while stakeholders with high power and with interests that are aligned with a change project are viewed as important allies (Hovland, 2005). These examples reflect the practical needs in the context where Stakeholder Analysis is often used (e.g. organizational change) but to some extent they stand in conflict with both sociotechnical systems theory in general and Human-Centered Design in particular. High and Nemes (2009) note that the object of a change process (e.g. increasing sustainability) is not always understood in the same way by different stakeholders. Since their framing of the problem may be very different, it may be difficult to relate their stakes to a common reference. As opposed to the “business” perspective on Stakeholder Analysis, High and Nemes instead present Stakeholder Analysis as a way of making sure that change process outcomes are adapted to real-world circumstances, and propose an alternative form of Stakeholder Analysis based on Checkland’s Soft Systems Methodology. A similar argument is made by Leventon et al (2016), stressing that marginalized actors should be allowed real influence in the change process.

5.5.1 LASH FIRE WP07 implementation of Stakeholder Analysis

A common use of Stakeholder Analysis is to support change processes in organizations or societies. In these contexts, stakeholders, their characteristics and their relations to the planned change are investigated in order to identify potential obstacles to the change process. In LASH FIRE Task T07.2, the primary use of a Stakeholder Analysis is instead to develop the research group’s understanding of the ship design domain and identify organizations that need to be included in later studies and design tasks. In a longer project perspective, however, the Stakeholder Analysis could very well be employed to ensure buy-in from key user groups, when novel design process activities or artefacts are discussed.

Continuing, it is also common that a Stakeholder Analysis involves some form of process analysis, relating stakeholders to work activities and outputs (see *Figure 1* below). For the process analysis part of task T07.2, however, concepts were instead borrowed from socio-technical systems theory.

The stakeholder identification process was carried out using snowball sampling, beginning with existing shipping company contacts, extending to the actors mentioned in the above section Interviews.

Stakeholder analyses as represented in the literature (e.g. Hovland, 2005) cover a wide range of stakeholder attributes, not all of which were deemed relevant for the present study. The following attributes were investigated:

- Roles
- Relations
- Goals
- Influence
- Knowledge
- Resources
- Conflicting interests

Due to the COVID 19 pandemic, practical hindrances limited the volume of interviews and organizations included in the Stakeholder Analysis. For that reason, updating of the analysis will continue throughout the project, using the results to inform stakeholder interactions and development activities. This iteration of the analysis had an emphasis on the future ship owner and that organization's interactions with other stakeholders, determining general design characteristics and supplier selection.

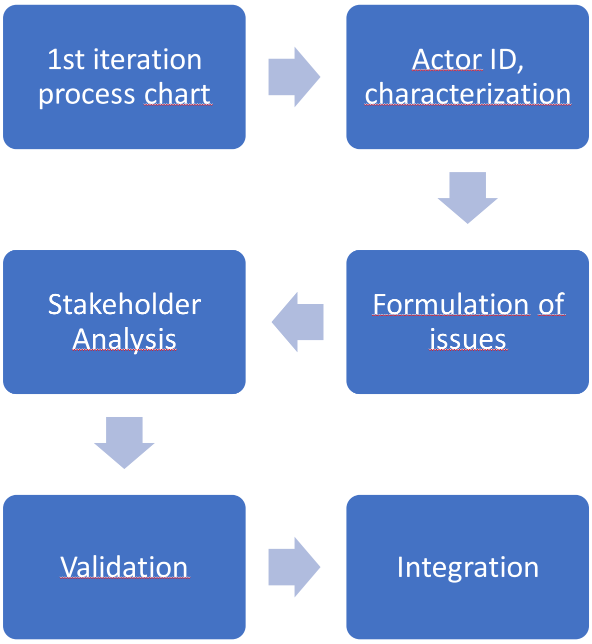

Figure 1 - Generic workflow for Stakeholder Analyses (Hovland, 2005)

5.6 Process analysis

Process analysis was carried out using concepts from Biazzo (2002), where the process is approached as an artefact in a sociotechnical system. Interviews were used to probe:

- Activities
- Interactions
- Artefacts

- Variance

Coding of interview data was performed, sorting information into process phases and types of process variance.

Developing an understanding of ship design and construction will be an iterative process continuing throughout LASH FIRE WP07 research activities. This iteration of the analysis placed an emphasis on how the shipping company/owner fulfils its interests as it procures a new ship. Results from this analysis has pointed to several variations and sub-activities within the overall process that will need further attention in later research. As an example, the present analysis does not cover the details of equipment manufacturers internal design processes, nor the internal dynamics of design firm process activities.

6 Representation of operative needs in ship design and construction

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Organizational studies reported in D07.1 were performed in order to shed light on the system of actors in the ship design process, describing their characteristics and involvement. The purpose of the stakeholder analysis was to achieve a better understanding of the ship design system and to establish contacts with key actors as a preparation for later development activities within LASH FIRE.

In this chapter, the Stakeholder Analysis is presented first, followed by a description of findings related to the ship procurement process.

6.1 Stakeholder Analysis

At this stage, the stakeholder analysis is limited to a table listing the identified stakeholders, together with certain attributes (see Table 1 below). In the single shipping company used for data collection in this iteration of the analysis, the owner, operator, project department and its design team all belonged to the same mother company.

Table 1. Stakeholder Analysis

Stakeholder	Roles	Relations	Goals	Influence	Knowledge	Resources
Owner	Future owner of the ship. Approves inquiry specification and building specification.	Design Team, Technical dept.	Fulfil market niche Long-term profitability	Strong, budget	Market knowledge	Production/market analyses from existing lines, market research
Operator	Will operate the ship	Owner, owner tech. dept, Design Team, Site Team	Well-performing, safe ship	Partial, through design team and site team	Operative experience, technical knowledge, route knowledge	Company contacts, e.g. previous operational personnel in the land organization
Tech. Dept.	Supports owner in specialist technical issues, reviews drawings	Design team, Design firm, Supplier, Shipyard, operator	Assist in realizing owner design objectives	Partial, provides input to design specifications and feedback on drawings	Specialist technical knowledge, regulatory knowledge	Regulation, standards, design guidance
Design Team	Manages the project, develops and manages budget	Owner, Operator, Tech. dept., design firm, shipyard, Supplier	Meet project budget, specifications, regulation, operator demands	Partial, leeway within budget	Project management, operative experience, technical knowledge	Regulation, standards, flag state rules, operator demands, previous project experience, base designs
Site Team	Follows construction at the shipyard on behalf of the owner	Design team, shipyard, suppliers	Verify adherence to specifications, give experience-based design input, resolve conflicts	Intermediate, represents the owner on-site, may introduce cost-increasing design changes within certain limits (negotiation)	Technical knowledge, operative knowledge, fire safety competence	Design specifications, work experience

Stakeholder	Roles	Relations	Goals	Influence	Knowledge	Resources
Crew	Design input, familiarization	Operator	A workable, efficient and comfortable workplace	Weak, partial representation in Design Team, enters late in the process (after delivery)	Operational knowledge about shipboard activities and technologies	Product manuals, procedures
Shipyard	Builds and commissions the ship. Issues building specification.	Project team, supplier, class	Build the ship according to specifications and class rules	Strong, influence over project expenditures, design, selection of designs/equipment	Technical competence, class negotiation	
Design firm	Designs the ship, from general to detailed characteristics. Issues inquiry specification.	Design Team, shipyard	Meet specifications, regulations, owner requirements	Partial, work according to design specification.	Naval architecture, production of 2d/3d drawings	Design specifications, drawings, models
Equipment supplier	Supplies shipboard systems or equipment	Design Team, Tech. dept, shipyard	Deliver system(s) according to specifications	Weak, supplies product according to shipyard	Specialist technical competence	
Fire safety consultant	Assists in design of fire safety installations where analyses are required to establish regulatory compliance.	Design Team, Technical Dept., Shipyard	Assist in fire code regulatory compliance	Weak, performs limited tasks according to contract	Fire safety analysis, dimensioning, technology	
Classification Society	Controls ship design and construction, issues classification	Shipyard, Site Team	Verify that class rules and regulations are fulfilled	Negotiate with shipyard over interpretation of regulations	Technical and operational knowledge, often extending to Human	Regulation, class guidelines and notations

Stakeholder	Roles	Relations	Goals	Influence	Knowledge	Resources
					Factors (in back office).	
Insurance comp.	Insures the ship, takes risk from the operator	Shipping company, class, IACS, IUMI	Minimize risk within the insured fleet	Partial, will sometimes enter into dialogue with shipping company about practices/design	Gathers both technical and operational knowledge	Heavy emphasis on existing regulation, IACS documentation

6.2 Process Analysis

A ro-ro passenger ship design and construction project involves a larger number of actors, interactions, activities, tools, supporting documents, resources and environments and can often span 3-5 years from project idea to delivery. Below, a design and construction process for a newbuild project is presented in the form of an annotated list. For this report, the analysis focuses on the future owner and its interactions throughout the process, and does not go into detail with regard to Design Firm or Equipment Manufacturer internal design processes. This translates to an approach acknowledging broad design activities concerning layout, equipment selection and integration. The list has been divided into segments for the sake of readability. Main activities have been typed in bold and key actors or artefacts have been italicized. Only steps that were deemed to have some relation to fire safety design were included, hence certain activities (e.g. stability tests, hull-related tests) were omitted.

Interviews have made it clear that there is considerable variance in the ship and design process, depending on numerous variables in the design context. Because of this, a separate section deals with examples of process variance.

6.2.1 Process outline

The following process outline is based on data from one shipping company and supplements the process outline in chapter 4 with additional details on activities and process artefacts.

1. Owner **ideation** based on market analyses (e.g. cargo traffic flows)
2. Creation of **project organization**: Formation of *steering group* that decides on particular design demands to be included in the specification. Formation of *design team* (*Naval engineer*, *electrical engineer* or *captain*, part time person from *technological dept*., *design firm representative*). A *design firm* is contracted to carry out *basic design* (in cooperation with the shipping company) and *detailed design* (against the shipyard, sometimes contracted for this by the shipyard)
3. **Project outline** (**Basic Design**) – Describes what the customer wants, including specific, non-regulatory demands as well as technical requirements (lane meters, cargo capacity, number of cabins etc). Negotiation of demands vs cost (between design team, operator and steering group). Development of *project outline*, *General Arrangement*, *Makers List* (e.g. vendors, system design characteristics, quality, future support)

DETAILED DESIGN AND CONTRACTING

4. **Shipyard tender and selection** – *Shipyards* compared e.g. on pricing, competence, experience, capacity. A *Ship Broker* manages shipyard contacts. Demands outside of regulation are negotiated (e.g. for fire safety applications). The culture of the shipyard, how willing they are to make changes and accommodate the design, is described as a decisive factor.
5. **Detailed Design**: Development of *full design specification* – May be based on a previous project. Reviewed by operator (and *charterer where applicable).*
6. **Selection of class** – *class review* of detailed specification. Class notations for additional items can be added (such as cybersecurity), but for an additional cost. It is generally up to the class to demonstrate that this is warranted. There may however be certain special class demands that are mandatory.

7. **Budgeting**
8. **Where applicable: Charterer contract**, based on charterer requests on top of the base design, in dialogue with the shipyard. Negotiation around possibilities, for example around bridge design or accommodation. The charterer may want to adapt design in accordance with already owned ships, e.g. to facilitate maintenance through using the system suppliers, or to simplify moving crews around.
9. **Contracting** – Ship construction contract covering *payment conditions* and timing, delivery times, guarantees, full design specification, makers list.

PRODUCTION DESIGN AND CONSTRUCTION

10. **Formation of Site Team** – *Site manager*, specialist competences in *technical systems*, *electrics*, *interior (passenger and hotel environments)*, *bridge*. Electrics is in charge of alarm system interfaces.
11. **Production design** - Shipyard develops *construction drawings*, *3D models*.
12. **Review** of drawings, models carried out by design team, class and flag state. This review may reveal HF/E issues.
13. **Construction** according to full specification. The shipyard has an economic incentive to do as much design and construction as possible themselves, since that is a way of saving project expenses.
14. **Commissioning** – Testing of all systems on board
15. **Sea trials** – Operative personnel represented
16. Modifications by charterer/operator/crew directly after delivery

A number of activities occur repeatedly or periodically throughout the duration of construction:

1. **Monthly meetings with design team, steering group, operator**. This is the way that the operator can introduce specific demands, e.g. around bridge design or specific fire safety demands.
2. **Weekly meetings between Site Team and Shipyard**
3. **Site Team inspections** – using the design specification as a base. Changes or corrections can be made within the specification, but if the shipyard does not agree that it is included, then it is considered a change order.
4. **Class inspections** – A limited level of detail, carried out strictly according to regulations and specific certificates.
5. **Change order** – The term for design changes during production design and construction. Fairly common and often originates from the operator/charterer, but can also come from the site team. Demands negotiation between site team and shipyard.
6. **Design input** from existing crew – possible and has been attempted, but uncommon. Crew availability can present problems for this, e.g. whether a suitable crew can be identified and can be spared.

6.2.2 Important phases for introduction of end-user needs

Interviewees mention two different phases where it may be especially important to address user needs such as ergonomics and usability. First, if end-users are included early in the project it will be easier to include their requests in design documentation, such as specifications and the General Arrangement. For example, GA workability issues may concern such issues as the placing of fire station(s) in relation to the roro space.

On the other hand, there are barriers to early, user-oriented design input. First, many details concerning the design of the ship have not been decided at this stage and consequently cannot be informed by the end user. Second, it can be difficult for seafarers to derive working environments issues from the textual and 2d design representations that exist at this stage. Lastly, several interviewees note that drawings and the General Arrangement will only allow project participants a limited insight to the final design. Issues concerning ergonomics and workflow may be hard to identify in two dimensions. The use of 3d models is steadily increasing to the point where it is almost considered a norm. However, fully detailed 3d models are only developed by the shipyard after the contract has been signed (i.e. 'detailed design'), which means that any substantial design alterations will result in a change order.

At the other end of the project timeline, many interviewees stress the importance of Site Team inspections and feedback on design. This feedback can also be considered an added value for the shipyard, in situations where the shipyard has limited experience from similar projects. Through knowledge developed within the project, the shipyard gains a market advantage in future tenders. On the other hand, any design changes that are not deemed to lie within the design specification will only be implemented at an additional cost. Modifications that are deemed to lie outside of the contract specification results in 'change orders'. In this negotiation process, aspects such as Human Factors issues may be explained away, e.g. "there will be a written procedure anyway". Interviewees also note that even if HF/E issues have been included in the design specification, demands such as "should be easy to maintain" still provides a lot of room for interpretation. It is also noted that design characteristics of this nature may be very hard to grasp at the stage of design specification, and that the Site Team is vital to spot e.g. impractical installations.

It is the Site Team that enacts the design specification and translates the owner's requests for the shipyard, and Site Team members may have a profound impact on final construction outcomes. This is described as a process of 'give and take', where a balance has to be maintained in order to provide for smooth owner-shipyard relations.

On a final note, the amount of explaining and/or negotiation on behalf of the Site Team is also, according to some interviewees, connected to the shipyard's knowledge of the customer and of similar projects. For example, with an increasing amount of ships being built in China, there has been an increasing need for on-site owner/shipyard interactions, but on the other hand, Chinese shipyard have often been accommodating when faced with owner demands. A factor that works against long-term relations between the shipping company and the shipyard is that shipyard cost is the main decisive factor for every new project. This fact makes it harder for the shipyard to build experience of the shipping company and its design preferences.

6.2.3 Process variance

While the aim of this first iteration has been to present a generalized ship design process, it has become clear that projects can vary greatly. In this section, different types of process variance have been clustered and are described briefly.

6.2.3.1 *Type of project or design product*

A first clear distinction between design projects is whether the purpose is *newbuild*, *retrofitting* (where systems or technology is added to an existing ship) or *rebuild* (e.g. where a ship is lengthened, shortened or where interior spaces are repurposed). According to interviews, these different project types carry with them different design constraints. Regulation is normally only retroactive to a certain limit, i.e. that only ships built after a certain year are affected. This should imply a higher level of safety for newbuilds, but as many interviewees point out, several other factors affect the actual quality of design and installations. A rebuild or retrofit project, on the other hand, must be planned around an existing ship design, which may already have gone through several modifications in the past. Moreover, it may be hard to argue for design changes of an existing ship that go beyond the main purpose of the project (e.g. lengthening), which means that design integration may suffer. Rebuild on particular has been pointed out in previous research (Bram et al, 2019) as the cause for issues such as confusing layouts, poorly placed equipment or inconsistent language in systems and signage.

Next, a ship can either be built for an operator belonging to the same mother organization as the project organization, or for an external operator. In the first case, the project organization normally engages in a dialogue with the operator earlier in the process.

The last type of design case is when the ship is built for chartering. In these instances, a distinction is made between *bareboat charter* and *time charter*. In the first case, the ship is chartered to an operator that arranges with its own crew, administration and maintenance. In the second case, the ship is hired for a specific time (normally 10 years), and the ship is managed and manned by the owner.

6.2.3.2 *Type of design product for a newbuild*

There are several ways in which a design can be realized to meet customer requirements. First, most shipyards have off-the-shelf designs to offer, which is preferable in cases where delivery must be quick. This variant implies the least amount of work for both the future owner, the project organization and the shipyard, while also offering the least amount of flexibility and tailoring in design. Second, the project organization may have its own base design for a certain type of ship, complete with template technical specifications. Third, the customer may request a fundamentally new design. Which route is preferred is, to the largest extent, governed by contextual factors such as the owner’s current fleet and market dynamics.

6.2.3.3 *Market dynamics*

The market for ships is greatly affected by global economics and varies dramatically over time, as does the amount of different types of ships in the second-hand market. When there is a high demand for ships and the shipyards are fully engaged (a ‘seller’s market’), shipyards are less prone to allow for design adaptations. Several interviewees agree that regulations provide quite a bit of leeway and that different interpretations can result in vastly different designs. In a seller’s market, more ships are delivered that fulfil regulations in the cheapest possible way. Similar results are seen when a ship is purchased solely on cost, with the aim of maximizing chartering profits. On the other hand, in certain markets, design firms can approach shipping companies with design prospects that go beyond regulation, e.g. in terms of bridge design.

Another market pattern that may affect user-oriented design is the shipping company appreciation of operational flexibility. Even though a Roro ship must often be tailored to the specific demands of its route (e.g. port characteristics), certain design solutions can make it more adaptable, making it easier to change the ship’s role within the fleet. Flexibility may also serve a function in a longer perspective. Ships typically have a very long lifespan and will often go through several transitions over the years, both in terms of ownership and uses. For a Roro ship it will often be necessary to tailor the interior closely to its current operations, changing elements such as cabins, restaurants and other amenities. These features will most often be modified by the new owner, while other variables such as lane meters or the type of engine can make the ship a unique product. As a result, flexibility is a design characteristic that contributes to second-hand value.

6.2.3.4 Ordering of project activities

In some cases, a full design specification is created before shipyards are invited to tender for the build. It was, however, not clear in which situations this pattern arises.

6.2.3.5 Contextual information available

When it comes to information that is used to steer early-stage design, several variations may occur. Sometimes the exact end-user (e.g. the charterer or what route the ship will traffic) will not be known, which naturally limits the possible extent of tailoring. This can present serious issues for fire safety design. One such example is whether a particular roro space will be used for cargo or private cars. The type of vehicles intended for the deck may have design consequences, for example when it comes to evacuation-related design. At the same time, the owner may have economic or other incentives to strive for flexibility. Traffics patterns may vary over the year, resulting in different cargo loading patterns.

Another variable that could affect design is what market the ship is aimed for. According to interview results, the way in which crew needs are valued and treated in design varies greatly between markets. As a consequence, if the ship is aimed towards a market where good working environment design is not a priority, then the builder may not be inclined to spend extra on such investments in a newbuild.

6.2.3.6 Variance in project documentation

The *design specification* and the *makers list* are two of the most central documents of the building process, but there can be many variations in their contents and use.

The amount of details in the **design specification** is always weighed against project costs, where more requests typically lead to larger costs. In many cases, a base design will be used, and for each change request, cost-benefit is assessed. Whether a request is deemed important may depend on if the particular design issue is within the current focus of the industry, operator or charterer. The amount of detail in the specification will determine how much freedom the shipyard has in production design. There may be negative consequences from a low level of specification (e.g. poor ergonomics or systems integration) but on the other hand, costs will also be lower. It is also acknowledged that demands concerning issues such as the crew’s working environment or usability may be harder to follow through in construction. Detailed demands will drive the price up, and more general demands such as “easy to maintain” can leave too much room for interpretation. As mentioned previously, a single design specification can often be interpreted in ways leading to very different designs. One interviewee mentions that for example, during the production of a recent line of ships, a detailed specification was developed at an earlier stage and used for tendering amongst shipyards in China, in order to avoid misunderstandings. This is also the reason why Site Team follow-up work is seen as so important.

A **Makers List** is only developed in those instances where the project organization and future owner want to specify system suppliers. In other instances, the shipyard is given more control over design and systems procurement. This process is cheaper and also gives the shipyard the option to build certain technical solutions themselves, thus saving money.

When a Makers List is developed, the design team may for example present the shipyard with three alternative suppliers. The shipyard collects price quotes, after which it normally suggests the cheapest one. Different systems may look very much alike when their specifications are compared, meaning that the design team must have special knowledge about suppliers to make an informed decision. It is not always allowed to specify makers for all fire safety products, and fire safety systems may be “cut up” between different makers (e.g. signs, pumps, pipes etc). This situation is typical for the Fire Alarm System. Even if the future owner has provided a Makers List, there is no guarantee that the yard will install a full integrated system provided by one single manufacturer. How systems are delimited can be described in the specification, but this depends on the interests of the owner/operator. Adding to the problem of integration, one supplier can also have several sub-suppliers.

6.2.3.7 Organizational variance

Even though the design team may have a similar structure in every project, there can still be many variations in its structure and activities.

Firstly, the operator organization can themselves form a project team. This seems to be particularly common in the case of smaller design changes. In most other cases (at least for the interviewed organization), a separate project department runs the projects. Secondly, whom is selected to be part of the design team will vary, depending on availability. It is acknowledged that individual team members may have very different skills and foci. Several interviewees state that the work of the Design Team and Site Team is colored by the experiences, knowledge and interests of its members, meaning that their understanding of fire safety design implications may vary. There is no guarantee that the interests and priorities of the Site Team and the future operator are in total alignment. Thirdly, it is not always possible to include project members with exactly the right operative experience. Team members are often senior officers and may have primarily sailed on other types of ships than the one at hand. In the studied organization, Site Team members are normally not recruited from the company’s operator organization, but instead from the internal project organization’s own ship operations. For rebuild projects in particular, if the site team lacks operational knowledge of the ship at hand, improvement opportunities may go unnoticed. Fourthly, it is not always possible for design team members to follow the project from ideation to delivery (i.e. move on to the Site Team). Lastly, the same individuals will not always be able to take part in multiple projects, not least because it implies spending long periods away from home.

A few reported examples of usability and ergonomics issues that have previously been spotted on the shipyard by Site Team members are narrow passages, hull openings needed for line of sight, the placement of lifting points, fire posts, changing rooms, placement of ‘fire stations’ in relation to the roro space, and the placement of the engine control room in relation to the engine room.

Some variations occur around the design firm. In some instances, the design firm is owned by the same group as the shipyard, something can facilitate communication between those two parties. When they belong to different organizations, the two are most often brought in at the same time, but sometimes the design firm may first be contracted to produce a basic design, which is subsequently used for tendering. Lastly, in some projects the design firm is only active in certain parts of the project.

6.2.3.8 Regulatory interpretation and implementation of class notations

On a last note, a few items regarding regulatory interpretation and class notations occurred during interviews. Firstly, is was noted that some regulation is written in a way that gives a lot of room for interpretation, allowing an operator to treat it superficially. Secondly, while some classes have specific guidance (e.g. on Human-Centered Design) and notations that deal more explicitly with crew-centered design issues, the owner/operator will have to pay extra for such notations to be included, something that requires special motivation.

7 Fire safety HF/E and regulation in the maritime context

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Although existing regulation goes a long way to ensure a basic level of fire safety in shipping (see Section 4.2), the way the regulatory system meets the industry can give unintended and even negative side effects (cf. Bram et al., 2019; Størkersen, 2018).

7.1 Different topics, different types of regulation, different consequences

The regulations contributing to maritime fire safety include different types of rules and guidelines, seemingly connected to the topics regulated (see Section 4.2).

On the one side, a large part of the regulations emphasizes on technical aspects and fire equipment, and these rules are prescriptive and specific (SOLAS, the FSS Code and classification standards). Crew competence certificate regulations are also specific (STCW). These rules are straight forward to comply with and to audit and sanction (Lindøe, Baram, and Renn 2013, Almklov, Rosness, and Størkersen 2014).

On the other side, regulations concerning design and safety management are often not prescriptive, but rather functional or only working as guidelines and thus scarcely audited. Functional regulations state a goal that the company should achieve (see Section 4.2.1). For the technical systems to be usable, and for training to come into use, there is a need for human centered design of technology and well-organized operations. We have seen that the regulations concerning Human Centered Design are few, and mostly formulated as recommendations or guidelines (e.g. MSC/Circ.982). Usability efforts on ships mainly extend to operational bridge functions such as navigation and maneuvering, while fire management onboard relies on functions distributed across the ships, involving many different systems and working environments (Bram et al, 2019). Here, previous research has made the case for a more holistic approach to design. Parallel with design, fire safety calls for safe operations and fire management. The relevant regulation intended to incorporate fire management to operational procedures, is the ISM Code (SOLAS-chapter 9, see Section 4.2.3.2). The ISM Code is functional and – with few specifications – requires that shipping companies implement safety management systems. The safety management system should unite operational procedures, and procedures to prepare for and respond to emergency situations, among other things. Main objectives are to ensure safety at sea through safe practices, risk identification and continuously improved safety management skills.

It is likely that if human centered unified design were made mandatory, it would be through similar functional regulation. To consider if a function is achieved requires much competence and efforts from all parts, in particular companies and auditors (; Lindøe et al, 2013; Almklov et al, 2014). To simplify safety management audits, operations are documented in detail. Documentation activity can potentially come into conflict with the goal of safety (Størkersen et al., 2020; Størkersen, 2018).

7.2 Regulation and the economic context

The maritime industry is a global industry that has to be concerned with costs. This can hamper its rule development and enforcement, since policymakers and regulators must take the industry actors' profitability into account, not only safety (Nilsen & Størkersen, 2018; Roe, 2008). The development of optimal safety regulations appears to be paralyzed in the existing maritime market (Størkersen, 2015): Since actors with power disagree, there is limited development in policymaking, and the quality of rules are not improved as much as one could wish from a usability and safety perspective (Knudsen & Hassler, 2011).

Due to the limits for policymaking, maritime regulation still has a heavy technical bias and provides relatively little guidance on topics such as usability and ergonomics (Bram et al., 2019). The economic context results in more rebuild projects than newbuilding. It is very common within the shipping industry that ships are re-sold and repurposed.

7.3 Regulation and audits

The economic context also makes shipping companies very focused on how to be auditable with the least effort, and usually not implement additional safety measures (Almklov, Rosness, & Størkersen, 2014). Shipping companies work intensely to ensure that regulations are fulfilled and that regulatory amendments are followed.

The strict focus on regulatory compliance maintained by shipping stakeholders directs much attention to certain safety topics (technical systems) while others may be overshadowed (design). A one-sided focus and overreliance on technical systems can suppress other organizational functions and thus increase risk in areas those systems do not examine (Power, 2004, p. 49). When so much time is spent on regulatory compliance, less time is available for other types of proactive safety work such as incident analysis and continuous improvement of the onboard working environment.

The compliance or auditability focus further influence safety and human centered design. Prior research (Bram et al, 2019) has shown that systems maintenance and revisions may influence usability. Firstly, revisions are sometimes carried out without consideration to user needs, thus running the risk of weakening existing designs. Secondly, crewmembers will sometimes engage with visiting technicians, hoping to communicate their concerns to the system supplier home organization.

Since regulatory compliance is one of the main objectives for an organization, aspects of safety that are not yet included in regulations or those that are not as easily translated into quantitative and measurable goals may be overlooked. Størkersen (2018) has elucidated how the safety management control regime is one reason for the last decade's many failed attempts to develop practical, useful safety management systems. Simple function-based rules like the ISM Code cannot be transformed into simple safety management systems in companies when the systems must be overseen by today's auditing regimes (Størkersen, Thorvaldsen, Kongsvik, & Dekker, 2020).

When shipping companies strive to comply with regulations in a context of limited profit, it is easier to comply with the specific technical regulations which the auditors are familiar with and often focus on (Almklov et al., 2014; Størkersen, 2018). At the end of the day, design recommendations and functional safety management regulation are not prioritized, even though human centered design and adjusted procedures could improve fire safety.

7.4 Regulation and operations

For seafarers at work on the vessels, the fire regulations are commonly encountered in the procedures that the seafarers are supposed to comply with. The ISM Code is in general translated into procedures in the safety management systems when it reaches the sharp end. Safety management systems include procedures for operations and emergencies, routines for training and risk assessments, maintenance plans, and so on (see Section 4.2.3.2).

Crewmembers in an earlier study (Størkersen, 2018) stated that procedures do not take variability into account, so procedures hamper them in skill- and knowledge-based decision making. Many shipping companies have so many procedures that seafarers report being "unable to think for themselves" (Størkersen, Antonsen, & Kongsvik, 2017). Radically restricted discretionary space makes it difficult for a crew to engage in abductive reasoning and consider how to handle variability and bandwidth management in operations under uncommon conditions, as is vital for a safe organization (Dekker, 2012; Hayes, 2010; Hollnagel, 2011; K. A. Pettersen, 2013; E. Roe & Schulman, 2008). Experienced personnel often improvise upon a set of embodied action alternatives to make operations work smoothly (see also Klein, 1993; March, 1994; Rasmussen, 1997; Rosness, 2009). Rule compliance can make personnel less equipped to handle surprising fire emergencies (Antonsen et al., 2012; Power, 2004), because handling variability demands practical competence, training, and discretionary space (Størkersen & Johansen, 2014). Unpredicted risks require a complementary approach to following rules, as they demand practical experience and the ability to improvise (Hale & Borys, 2013a; Hohnen & Hasle, 2011). Given the inherent variability of maritime operations and particularly fire situations, seafarers simply must have competence and discretionary space.

8 Fire Alarm System Interface Design Requirements & Guidance

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8.1 Background: improvement potential

The following themes were developed at the beginning of LASH FIRE WP07 activities to represent improvement potentials in the development of fire safety systems. The themes are based on the findings in the projects Firesafe II (Leroux et al, 2018) and SEBRA (Bram et al, 2019).

Consistency

The need for interface design consistency is present in several ways.

Representational consistency: In previous research (Bram et al, 2019) as well as in internal LASH FIRE studies, a recurring theme is the often illogical – or inconsistent – presentation of detection frame numbers, detection sections, drencher section, CCTV numbers etc that are displayed on the alarm panels, with a lack of 1:1 relationship between the physical referent and the visual references. Another relevant issue is *resolution*; if not only the right detection sections, but also the individual detector, can be easily identified, conditions for effective alarm management will improve greatly.

a) Alarm presentation scheme consistency: there is a need for a more consistent alarm presentation scheme, where wording, vocabulary, colors and position of indications are standardized and easily recognizable.

b) Design philosophy consistency: there is a need for a more thorough design philosophy for alerting and presentation across all installations or systems on the bridge, not only alarm panels. This also points towards systems integration.

Integration

Several aspects of integration need to be taken into account:

a) Alarm/signal integration: There is a need for better integration of different alarms on the bridge and their respective signals in order to improve the environment for communication and reduce the need to mute alarms

b) Information integration (cognitive): The need to integrate different pieces of alarm information is commonly reported. Examples could be the need to combine data such as section number, drencher section and valve number to understand the most probable location of the fire. This may put a high cognitive load on the person receiving the alarm. Another example is the use of cargo information to make sense of the fire situation, for example the presence of Alternative Fuel Vehicles (APV).

c) Information integration (physical): this refers to problems of information distribution and sharing. One example is the problem that different systems representing different pieces of information may be localized in different parts of the bridge.

a) System integration: Fire alarm interfaces should be seen in connection with other systems with which they may compete for the crew's attention. It is therefore recommended that all systems on the bridge and in other control environments should be analyzed for the potential of integration to obtain more holistic and seamless solutions. This integration also holds the challenge of harmonizing systems that come from different suppliers. One possible candidate for integration could be ventilation management. CCTV is also mentioned as a system that could be integrated into a fire management system. This points towards solutions often referred to as 'integrated bridges'.

Information quantity

The amount of information available is a major issue for effective fire incident management, and both too little available information and too much information presented can be a problem.

a) Too much information presented: If there is more information pushed out to the crew than they are able to handle and process, this can hamper fire management. Hence there is a need to critically assess the information presented on the alarm panel and planning surfaces. One expression of this problem is the escalation of alarms noted in previous research. Alarm aggregation, history, silencing and recurring alarms will all be important research topics for Action 7A. Here one will have to consider existing regulations of allowable alarm aggregation.

b) Too little information presented: While information overload can pose a problem, particularly as incidents evolve, an equally serious problem can be that important information is *not* available. This is related to the issue of information integration, as this information may be available elsewhere – for example temperature readings, stowage plans and system status (e.g. whether drencher system is activated, or if a suppressed alarm still qualifies trigger conditions). New alarm panel designs should take into consideration types of information that is not available today, but that should perhaps be so in the future. Several such possibilities are mentioned in the section "Potential functionalities".

Information salience and noise

It is not only the amount of information – too much or too little – that affects the usability of the alarm system. How the information is presented is of large importance, and a major design issue. The art of presenting information clearly can enable the user to make sense of much larger amounts of information. It is a dominant finding from earlier research that there is a need for better design of maritime fire alarm panels, in order to present information in a more clear and understandable manner. Research topics include:

a) Clear and unambiguous representation of fire location and activated detectors. There is a need for a design best practice on visualizing the alarm location, and possibly on detector location descriptions. This information is important in all phases of fire management. One important case is the interaction between the OOW and the runner during the early stages of fire identification, where it can be challenging to assess whether the runner is at the right location. This issue borders on familiarization, which has also been identified as a weak link and where different kinds of support could be envisioned. In turn, such supports could also be used for the purposes of training.

b) False alarms: The number of false alarms is a recurring problem. It is a nuisance in daily work, and it can reduce the motivation of the crew to quickly attend to alarms. If these alarms – both those from false sources and those from alarm failures – cannot be eliminated, they may perhaps be reduced through design, in a way that effectively remove this excess information. Although false alarms can also be seen as a case of “too much information presented”, it is a special case with so many particularities that differ from panel design issues, and hence it is treated as a separate point.

Simplicity and affordance

A previous operator survey within LASH FIRE underscores the importance of systems being simple enough so that the crew can operate them without the need for advanced training or written procedures, and that fire alarm panels should easily *provide* the wanted response from the operator. Relevant topics include:

a) Affordance: In terms of affordance, interface design should clearly communicate its functions and the consequences of different actions, so as to encourage efficient work practices and lower the threshold of interaction. A related, still relevant topic is the extent to which the system is documented and accompanied with clear and user-friendly instructions, either separately or integrated into the system.

b) Lenience: IR05.8 stresses that interfaces should be designed so that the risk of accidental inputs is minimized – for example in the case of touch screens. It is also important that the consequences of actions are clear, and that it is easy to recover from erroneous inputs.

Temporality

In the management of a situation that extends over some time, it is of major importance that the crew can keep track of the *development* of the situation. One aspect of this has to do with the way the alarm history is managed and made available. In many of currently available solutions, there is a risk that crucial temporal information gets lost, or that it is too demanding to look it up in the heat of the moment. This also connects to the point regarding information integration.

Recognizability

In an internal operator survey, the prospect of mimicking aspects of interface design found in other well-known systems or commonly used IT devices is mentioned. Without having researched this, it is our impression that such software is increasingly accepted in high-risk industries (e.g. standard Microsoft products in aviation), something that also may offer opportunities for learning and sharing across industries.

Other potential fire alarm system interface functionality

Apart from the more conceptual requirements of the prior sections, previous studies have resulted in a large amount of potential additional functionality of future fire alarm system interfaces. These ideas are presented with two caveats: First, the list is almost certainly not exhaustive. More time must be spent on needs assessment and brainstorming together with relevant actors, such as crews, nautical engineers and system suppliers. Second, the ideas listed below must be evaluated further in order to prioritize them and safeguard against unwanted side-effects.

a) The right level of information detail for the situation e.g. information of what type of sensor is activated

b) Temperature readings directly on the panel

c) Easy deactivation of fire detector loops

d) Clear indication that all sensors are not up and running. Alternative designs to increase safety and situation awareness when parts of the fire alarm system has to be inactivated, for example due to loading/off-loading or hot works

e) Connection to CCTV system

f) Visualization of electrical/other faults, support in telling them apart from real fire alarms

g) Beeper or mobile phone could be connected to alert the OOW when the ship is berthed with no watch on the bridge or in the CCR

h) Possible integration of digital stowage plan

i) Have the system propose an intelligent first line of action

j) Language barriers needs to be considered

k) Listing of equipment on board could be integrated into the AIMCS

l) Support for positioning of crewmembers

m) Support use for fire training purposes

n) Interface for land-based surveillance and/or support

o) Alternative approaches to solving the situation with competing alarm signals on the bridge besides existing regulation on sound pressure levels (FSS Ch. 9 §2.5.1.9)

p) Standardisation of manual fire alarm call point feedback, to avoid confusion about its state

q) Fire alarm system interface design needs to acknowledge “system operating conditions” as listed in IR04.6 2.2.2.6.

The above themes formed a point of departure, together with research and guideline literature on human factors design (see Background). In the following sections, functional and design issues that are recommended to be prioritized are grouped into categories that are eventually discussed as aspects of integration and standardisation.

8.2 Prioritization and elaboration of user needs/implications

The discussions and interviews with crew members that interact with alarm panels through their formal roles in fire or fire related situations resulted in a number of issues and themes being elaborated. In the following we report these issues and themes, before we discuss them in light of recommendations from earlier research (Firesafe II and SEBRA), generic human factors design theory and maritime design guidelines in section 6.

8.2.1 Existing alarm panel systems – heterogeneity and adaptation

There is very low degree of standardisation of fire alarm panel solutions across vessels. Unlike the norm in aviation, each ro-ro vessel has its own history of commissioning, design and construction, and as noted in the previous chapter on ship design practices, the design process involves a number of stakeholders with a variety of interests that influence outcomes, including design and buyer choices. Further, rebuilding may lead to additional rounds of change in system types and design. As a result, few ships are similar when it comes to alarm systems and panels, even though they may belong to the same ship operators; there is a high degree of heterogeneity. One example is a vessel where the original, text-based fire alarm panel was supplemented with a linked computer with graphical software that provides additional information in case of alarms. The bridge officers were very satisfied with this solution, although they described it as not completely 'formal'.

Another aspect of the existing heterogeneity is the mix of digital and material artefacts making up the systems. Many alarm panels have so limited functionality that information that is provided on the screen needs to be deciphered by looking up the meaning of codes in physical binders (apart, perhaps, for the very experienced officers who may have memorised this information). Also, although the panel systems may provide sufficient information about fire status, they do not facilitate organisational response; the crew usually depend on laminated GAs, marker pens and the like. Paper-based checklists are also central in an early phase of fire situations. These are likely to be company specific, but the templates tend to be modified for the individual vessels.

Heterogeneity as such is not described as problematic by the informants, but the poor usability of some systems is. Hence, it seems that it is not more standardisation responding to regulative requirements that is desired by the crew, but more user-friendly systems that meet operational requirements. Many of the officers we have interviewed have experience from different ships, and frequently mention other vessels with more user-friendly systems.

8.2.2 Integration

Integration is a recurring issue when we discuss information access in connection with fire alarms. Valuable time in stressful situations is sometimes spent on having to check in manuals to get the information needed. One of our informants describe it like this:

"I know my ship, but sometimes I have to go into the manuals to get the information I need. Have to consult with my chief engineer, I'm all over the place. You have to move around and consult many different systems, panels, combine and draw my conclusions. Luckily, I have ten years on this ship, I know it well, but sometimes very hard to keep overview."

We pursued this issue further and asked our informants to explicate the fragmentation, and to reflect on what type of systems and information that ideally should be integrated in a future more user-friendly alarm system. The following points were mentioned:

Temperatures. The ability to monitor temperature status and temperature development at all sensor location in ro-ro decks is very important and should be integrated in an improved alarm system surface.

Hi-fog. It would be very useful (important) to be able to start hi-fog from the same surface from where one monitor temperatures. In that way one may start cooling without sending people to activation locations.

Sector correspondence: On the fire system surface, there should be unambiguous correspondence/relation between drencher sections, roro-space sections and detector sections/locations. When there is a fire, one should straight away see the relevant section of the drencher system, so that one doesn't need to walk to another overview of the drencher system and find out where to open.

Closing of fire doors. It should also be possible to close fire doors from the same surface from where temperatures are monitored, and extinguishing systems are activated. It should not be necessary to go to the location and close them by hand.

Car decks and cargo. Car decks and cargo information should be integrated into the system. Today they know where and what the dangerous goods are as long as it is declared in advance, but nothing is known about the cargo of the next truck. Also, there are no strict systems for placement of electrical vehicles or other APV. It may take up to half an hour to get to know what is inside some of the trucks. “It should be handy, only one click, and get the cargo manifest and the trailer on the right” (bridge officer). Today, everything is in papers, and it takes time get the papers up on the bridge.

Ship stability, ballast. While ship stability is *normally* not a challenge during drencher operations, both past accidents and experiences from our informants' report that both cargo and debris may clog the scuppers and lead to water accumulating on the deck, with loss of stability due to the free surface effect. The ballast management system is a separate system, but on direct questions our informants say that it would make sense to have ballast management integrated into an FRMC system.

Cameras. There are usually many cameras on the ships, but they are “unfortunately not” (bridge officer) connected to the fire system. One of our informants tells us of his dream that one day, the whole camera system will be coupled, making possible to use them more actively in fire management.

8.2.3 Alarms

Our informants tell us that alarms go off “all the time” on the ship – sometimes false, sometimes fault, sometimes real, and that is an enormous stress factor for both crew and passengers. One of the bridge officers complains that in their system, you cannot isolate an alarm before it goes off – only then you can isolate it. In stressing situations, this can lead to messages given to “press mute every time you hear an alarm!” – with the risk that an alarm from the deck above where one believes the fire to be contained, is muted.

On ‘traditional’ panels there are few possibilities to turn off the sound in order to create less stressing working conditions during fire management/crisis handling.

8.2.4 Wayfinding/signage

The alarm panel will typically give a short text information about the room, e.g. “engine room” or “steerage room”, and then a frame number, to those who do not have detailed experience with the actual ship it can be confusing, and time is lost when discussing the interpretation of the alarm message. In addition, there is sometimes confusing ways of naming stairwells – using both colours and letters. A standardisation both of the material environments and the textual/graphical referencing would be a big advantage. This must in case be seen in conjunction with the terminology used for the same areas in other contexts that fire management, so that also the terminology is integrated.

8.2.5 Organization

It would be very useful to have the same system in the engine control room as on the bridge. Also, it is important that the system contains info about who has acknowledged an alarm. Decisions are made on the bridge and in the engine control room, so alarm system info is not needed elsewhere.

A challenging task is to keep control with the presence of the individual members of the fire team - who they are, where they are, the equipment available for them. Sometimes it can be a real problem to find people.

One bridge officer refers to a ship operator where they had a fully digital and clickable GA. By clicking on the GA, arrows pointing to emergency exits would appear, in addition to information on which ways one could choose between to enter the area, information about the localisation of detectors and extinguishment equipment, all useful for the establishment of a staging area. While this information is also available on paper, our informants hold that it is not as efficiently highlighted on paper.

9 Discussion

The work reported in LASH FIRE D07.1 has been carried out to provide a baseline and requirements for future LASH FIRE development and design activities. In this discussion, the most important findings related to such activities are discussed and elaborated. The discussion has been divided into sections reflecting the overall report structure, representing the topics of ship design processes, regulation and fire alarm system interface design.

9.1 Fire safety HF/E in ship design and construction

Main authors of the chapter: Staffan Bram, RISE

Interviews conducted to support stakeholder and process analyses reveal that actors in the ship design and construction process are driven by interests that do not always overlap, and that circumstances affecting the individual design project may steer stakeholder actions in very different directions. In the sections below, the influence and incentives of each stakeholder has been paired with factors constraining their contribution to shipboard fire safety. These constraints are developed further in the following sections of chapter 9.1, ending with a number of suggestions towards future LASH FIRE research activities.

9.1.1 Stakeholder fire safety influence, incentives & constraints

The shipping company **OWNER** is a key stakeholder in the ship design process and has a large potential **influence** on fire safety design. They have inhouse operative experience to inform design decisions, they can specify makers capable of satisfying their expectations, they can contract shipyards that are willing to accommodate their requests, and they can follow the construction process to make sure that their design objectives are fulfilled. This influence also translates to several possible **incentives**. By improving fire safety HF/E in ship design, they may avoid misunderstandings and late changes during the construction phase, while in a longer perspective minimizing the occurrence or consequences fire incidents. Since fire safety HF/E is so intimately related to overall ship ergonomics, such design may also improve crew wellbeing, helping with crew retention. For some shipping companies, genuine care about the crew and passengers may be a strong enough incentive to boost fire safety. It should also be noted that some shipping companies may have the opportunity to inform the IMO regulatory process. On the other hand, both shipping company influence and incentives are associated with **constraints**. Interviews suggest that inhouse operative competence is not systematically leveraged to inform design and that changes to entrenched processes and activities may be met with resistance. The Makers List is not applied in all projects and selected makers will not always get to deliver a well-integrated system. Most importantly, the more details that go into the specification, the more costs will increase. The selection of shipyard is also heavily influenced by current market conditions and economic constraints, and the shipyard’s willingness to accommodate owner requests will vary, depending both on economics and on regional/geographical variations. Furthermore, since there is no current way of proving the value of HF/E interventions in fire safety design, all of the potential incentives remain to be demonstrated. In this context, it could even be argued that design solutions that deviate from well-known standards introduce unknown risks in operations. Continuing, a large fire on a ropax ship could have severe implications for the shipping company’s brand, but for ships that mainly carry cargo, insurance may take away incentives for fire safety improvements beyond regulatory demands. In addition, interviews suggest that in a global perspective, many shipping company owners simply do not value safety beyond threats to their business model and profits. Lastly, it should be noted that not all shipping companies have a long-term interest in the ship, or in the well-being of its crew and passengers, meaning that long-term and human benefits of HCD may be disregarded.

The shipping company **OPERATOR** may exert an **influence** over fire safety design through the participation of operative personnel in the **DESIGN**- and **SITE TEAMS**. Everyday operations may also provide opportunities to influence fire safety equipment and installations, e.g. in the case of replacement or retrofitting. Among operative personnel, there is a strong **incentive** to improve fire safety design. A fire onboard is a direct threat against the crew, whose members must also work to limit its consequences. On the other hand, several **constraints** apply. Previous research has shown that the understanding of fire management success factors often differs between the operator’s shipboard and land organization. One explanation for this is again that the benefits of revised or added fire safety installations may be difficult to prove when cost-benefit is assessed. Another explanation is the traditional regime of safety and quality management described in previous research (Bram et al, 2019), for which the main focus is regulatory compliance, and where the connection between working environment design and fire safety performance is not consistently taken into account. In the interviews, several persons also suggest that different stakeholder departments may also have varying priorities and understandings of fire safety. In terms of design process involvement, even though operative personnel is routinely included in the studied project organization, that organization may find it equally difficult to identify and demonstrate potential fire safety improvements in design. Furthermore, since operative needs may be difficult to translate into design specifications, such design improvements mainly hinge on the (somewhat arbitrary) experience, interests, negotiation skills, tenacity, status and home-organization support of design/site team members.

The **SHIPYARD** can be considered the other main stakeholder. The yard has a profound **influence** on fire safety design, through the way it negotiates and realizes the future owner’s design specification. Some interviewees suggest that the shipyard’s main **incentive** is always profitability. From that perspective, the shipyard could benefit from HCD in fire safety design, because more careful design planning usually translates to a reduction in late, costly alterations in design and construction. In addition, good design solutions can be carried on to future projects and off-the-shelf designs. With time, a shipping company may come to prefer a shipyard that has the ability to accommodate operative needs. On the other hand, several **constraints** work against these potential shipyard incentives. It is widely known that shipyards often walk an economic tightrope, to the point where they sometimes stand or fall with the next build. The shipyard build process is heavily streamlined to minimize costs and the yard may fight fiercely to avoid any design tailoring that goes beyond standard solutions. Any costs invoked by special design requests will be directed back to the future ship owner, whom may have few own incentives to buy a ship that exceeds current regulation. Furthermore, the shipyard can save money by using their own designs or mixing installations form different suppliers, which may undermine both usability and integration. The yard has no long-term responsibility for the ship, and even if they wanted to promote good relations with the owner, when the owner wants to build a new ship, the main decisive factor for shipyard selection is likely to be economics.

The work of the **DESIGN FIRM** relies heavily on future owner requests and design regulation, but the firm may **influence** design outcomes through particular experiences and in-house fire safety design concepts. The firm may have a pronounced **incitement** to accommodate owner requests given that both the owner and design firm may benefit from a long-term business relationship. On the other hand, project dynamics may introduce various **constraints**. Given that the design firm must also contribute to cost minimization, there will typically be little room to introduce design elements beyond regulatory demands. Regulatory compliance is important to the owner, and since compliant fire safety design does not equal workable or ergonomic design, actual design output will vary greatly. Suggesting cost-equal but alternative design may instead be perceived as a risk, an obvious target for audits. Furthermore, interviewees note that the early phases of a design project may take place under considerable financial constraints, leaving little room for explorative design work such as extended user studies.

The **MANUFACTURER/SUPPLIER** will only **influence** fire safety design outcomes in the case they are selected among other alternatives. If they are, given that they offer a well-designed product which is also implemented according to designer intentions, then their product can positively affect fire safety performance. Interviewees mention the existence of several suppliers/manufacturers that have a pronounced interesting in developing 'user-friendly' systems, e.g. fire management systems. On the other hand, fierce competition and cost minimization can introduce severe **constraints.** Suppliers are primarily compared on cost, and even if certain shipping companies prioritize safety and are willing to spend money on fire safety design, this is not the case to the large bulk of owners. Furthermore, shipyard economic incentives may also threaten the design concept of supplier products, e.g. by mixing and matching between components from different suppliers, nullifying supplier attempts for design integration.

The **CLASSIFICATION SOCIETY** has a clear **influence** on ship design through the way in which it interprets and enforces regulations (in the form of class notations), sometimes with its own additional demands. Many classification societies have developed detailed guidelines concerning Human Factors, Ergonomics or Human-Centered Design issues. It is also increasingly common that the Flag State delegate responsibilities such as inspections to the class, further increasing its influence. The class **incentive** to contribute to fire safety design mainly lies with fulfilling its responsibilities i.e. ensuring regulatory compliance. However, both influence and incentives are associated with **constraints**. Non-mandatory class notations may provide a wealth of information on topics such as Human-Centered Design, but these notations will only be implemented by a small portion of shipping company owners. With regard to the design process, Design/Site Team members testify to the fact that class inspection of drawings and construction adhere closely to regulation (in accordance with class responsibility), naturally limiting the inclusion of fire safety HF/E.

The **P&I CLUB** may **influence** shipboard fire safety arrangements by the extent to which such design is part of insurance demands. Interviews suggest that demonstrable, safety-increasing design on behalf of the owner may lead to lowered insurance premiums. There should be a clear **incentive** for the P&I Club to promote safety-enhancing design, given that it would contribute to risk reduction. On the other hand, demonstrating such a reduction is associated with the same **constraints** as noted in other stakeholder interactions. If the P&I Club is to accept the risk-reduction potential of fire safety HCD, then that potential must be demonstrated in a way accepted by the industry, something that again invokes the discussion over function-based versus prescriptive regulation, and how difficult it may be to prove both the worth and the fulfilment of functional goals for operative fire safety.

In this comparison between stakeholder influence and incentives, certain constraints appear to dominate. Economic factors, design process implementation, the project scope, formulation/verification/validation of design requirements, and the way fire safety is pursued and managed through regulation, safety and quality management all appear to have large consequences for the way in which fire safety design varies among ships. In the following sections, the implications of these constraints are explored further.

9.1.2 Economic constraints in fire safety design

Data generated in the present study, as well as previous research (Bram et al, 2019), suggests that the primary factor influencing fire safety design is project economics. The shipping company tries to protect or strengthen its position on the market through expanding its fleet, and in that process, variables that have a direct relation to profitability (such as lane metres or the amount of cabins) dominate the discussion. Whether the new or rebuilt ship is a good investment will only be proven after years of service, making it so that short-term savings (i.e. during design and construction) dominates over long-term operational benefits. Since HF/E inclusion in fire safety design is not the norm (de Vries & Bligård, 2019), pursuing such design parameters goes outside of standard practice in design and construction, resulting in a (feared or real) economic penalty (Costa, 2018). It should also be noted that the financial strength of shipping companies may vary greatly, and that many will simply be looking to buy the cheapest possible ship that can still generate profits, e.g. off-the-shelf newbuilds or older, refurbished ships.

Looking at the other main stakeholder of the process, the shipyard will have streamlined its design and construction process to minimize any variance and protect its business, and will enter into hard negotiations around any demands that have not explicitly been included in the contract. However, minimizing cost in both design, procurement and construction may have consequences for fire safety design. When equipment is primarily chosen on price, other characteristics such as usability or design integration may suffer. It should also be noted that even though a ship may have a confusing layout or a poorly integrated alarm system, it can still be perfectly compliant.

The economic reality of shipbuilding has to be taken into account when plans are made to forward the position of usability and ergonomics in fire safety design. Since economics enter into most discussions about onboard working environment design, it seems motivated to look for ways of introducing HCD without threatening the business case for any stakeholder. First, shipping companies may be convinced to make additional investments in fire safety that go beyond regulation, e.g. if risks have been proven by accidents or if benefits have been proven in research. However, such a strategy would only apply to a select few organizations. A second route, if benefits can indeed be proven, would be to demonstrate how fire safety HCD objectives can be fulfilled without cost penalties. Organizational change will always be associated with some cost however, so even it could be shown that a shipping company could maintain its expenses and also realize a higher level of safety, the transition to HCD practices would come at a price. That need not be a problem, however, if long-term benefits (e.g. safe and/or efficient operations) could be demonstrated, although such a scenario presupposes that the owner actually has a long-term interest in the ship. On the subject of cost-benefit, it may be important to dwell on what HCD practices actually imply for fire safety design. Changing norms and standards for general installations and equipment need only introduce a higher cost in the very beginning, while actual user-centered methods involve more people in the process, which may inevitably translate to a higher design process cost. That said, the traditional design process does also have economic drawbacks. For example, a common contributor to increased costs (both for the owner and shipyard) is post-contract changes in design and construction, often stemming from design specifications that are miscommunicated or too undeveloped.

Looking at the shipyard, in order to still minimize cost, the owner and yard must primarily agree on a design specification that also realizes HF/E goals for fire safety design, and that specification cannot be associated with higher costs than standard solutions. If design tailoring is to be avoided, that either translates to changes in regulation, standards, or standard design firm/shipyard practices and designs. This last notion ay be equivalent to identifying elements of fire safety design that maximize operational efficiency and effectiveness, and at the same time require minimal tailoring to the individual operator. In the case where user-oriented fire safety design characteristics cannot be argued to lie within existing regulation, either the owner must be willing to pay extra, or design firm and yard design practices must be moved towards a usability-centered reading of existing regulations.

9.1.3 Design process barriers to fire safety HF/E integration

In addition to economic constraints, this study shows that there are also factors related to organizational processes and everyday shipping company operations that can make it harder to introduce operational experience and requirements into fire safety design. Judging from the experiences of interviewees, even though the studied organization has made a practice of senior officer participation in Design and Site Teams, the extent to which operational experience and work-oriented knowledge translates into design varies.

Many researchers seem to agree that user involvement in design has the best outlook when performed in the early stages of a project. Doing so allows users to affect basic design features and will decrease the risk of runaway expenses. On the other hand, this study as well as previous research (Gernez, 2019:2; Solesvik, 2011) shows that several obstacles exist. Firstly, the exact user group or operational scenario is sometimes not known until the project has progressed significantly. Secondly, ship design is an iterative process that continues throughout the project, even at the construction stage. Results indicate that while some problems with usability and ergonomics may be spotted in early 2d representations or specifications, others only appear when experienced end-users interact with 3d or actual physical environments. However, when 3d or physical environments are ready for review, any changes will introduce additional costs, and some aspects of design are impossible to change. Even if end-users are indeed involved in the Design and Site Teams, there is no guarantee that the right experience is used effectively. Gernez (2019:2(argues that user involvement is not only a matter of involving senior officers, there also has to be a method to elicit and operationalize their knowledge. In addition, the extent to which different aspects of operational and safety knowledge exists in the group is somewhat random. Involving additional crewmembers in design work may be problematic, because they will typically either in operational duty or on leave. If fire safety were to have a more prominent role in team decision-making and design input, then it is likely that team reinforcements are necessary, e.g. in the form of task-specific training or fire safety HF/E design heuristics.

Problems with crew representation again invokes the discussion about what level of direct user involvement is actually necessary in order to realize more usable and ergonomic fire safety installations. Problems with early crew project involvement seem to speak for activity-centered design firm approaches as proposed by Gernez (2019:2) and Lloyd's Register (2014). At the same time, previous research has noted that fire safety is affected by many general design characteristics of the ship. It may be questioned whether a design firm could rise to the task of comprehensive field studies and activity analyses and still remain competitive, even if activities were limited only to those relevant for safety. It may be that for newbuilds, large improvements could be made with generalizable modifications of safety-related design. Here it would be important to identify exactly how fire safety HF/E translates to aspects of ship design, and when those aspects can be addressed during the progression of specifications, designs and construction.

On the side of the spectrum, refurbishing or repurposing of existing ships is associated with many more design constraints. Here, it may be more important both to explicitly include operational feedback and to look critically at the existing onboard environment, seeing that it may have gone through many design evolvements without much consideration to operative demands. By contrast, following such practices may be particularly hard for design projects on existing ships, because both budgets and regulatory demands may be lower. Lastly, no matter if a ship is a newbuild or bought second-hand, a shipping company will often want to adapt it to their own design preferences (e.g. in terms of equipment selction or interior design), and there could be a window of opportunity to make HF/E part of that shipping company design profile, given again that costs can be minimized.

9.1.4 Regulation, verification and validation of fire safety design

The review and analysis of the regulatory system and relevant regulations (see Section 4.2 and Section 7) shows that how regulations are written, how the regulatory process works, and the maritime market situation, gives a technical bias to how shipping companies comply with regulations. When this regulation is adapted by shipping company organizations, given their own organizational dynamics, the consequences of the regulations are not always as intended. The companies have marginal profits and choose to comply with the regulations that are prioritized in audits. The regulatory process (and also other actors like insurance companies) gives much responsibility for audits to classification societies. This implies that classification societies' practices and emphasis on technical and specific systems influences the shipping company priorities to a great degree. The fact that fire safety is mostly regarded as a technical problem, and that fire management should be incorporated in the safety management system, causes it to be downplayed in compliance and enforcement.

As noted previously, even though a ship fulfils all fire safety regulations, ship design may still cause problems for crew fire safety activities. This suggests that the range and/or characteristics of existing regulation is insufficient. To some extent, it should be acknowledged that regulation is unlikely to cover all possible risks in a highly heterogeneous industrial branch like shipping. The consensus-based maritime regulatory process makes sure that regulation is not passed that is too specific, e.g. too closely adapted to a particular economic context. The flipside is that the regulatory progress is slow and full of compromise, sometimes stalling safety-enhancing regulation that is deemed too costly.

When additional, safety enhancing design requirements are brought into a project, cost will normally increase. It could be argued that for an organization to pay extra in order to fulfil design requirements that go beyond regulation, that signifies a more mature organization and perhaps not the most important target group for safety interventions. Several conclusions can be drawn from this. Either regulation needs to be augmented to better represent the multi-faceted nature of fire safety. The question then becomes how fire safety HF/E could be turned into effective regulation without immediately being rejected by IMO members. At the core of this prospect is the question of fire safety HF/E economic feasibility discussed previously. A very important issue is whether incentives for enhanced fire safety design could be found where stakeholders receive other benefits than compliance in return for safety investments.

Regulation invokes the discussion of fire safety regulatory audit and design follow-up. For either of them to be possible, fire safety HF/E must be translated into suitable design goals, as well as clear criteria to help judge whether those goals are fulfilled. A key element in such demands would be to tackle design fragmentation where systems and equipment from different suppliers are mixed and brought together without conscious, user-centered integration. The owner would benefit from such goals and criteria through smoother project verification and validation, safer operations and possibly also from lowered insurance premiums, given that the case for fire safety HF/E can be made among P&I Clubs. These are a few possible incentives outside of regulatory compliance. On the other hand, shipyards having to adapt their products would likely be met with resistance, although it could do away with some time-consuming, construction-stage negotiations around fire safety installations. In addition, function-based regulatory demands that are not limited to technical aspects of ship design places additional demands on inspectors and support for inspectors in the ship design and construction process.

9.1.5 Operations-stage fire safety design management and improvement

Several persons interviewed for this study have commented on the fact that different shipping companies have very different ways of approaching safety, and that some organizations are very reluctant to invest in safety-promoting solutions. At the same time, it has been noted that LASH FIRE mostly engages with shipping companies that have a pronounced interest in safety development. It may be questioned whether current attempts in the industry to promote HCD succeeds in targeting the group of owners and operators that are in the greatest need of ship fire safety interventions. As an extension of this discussion, it can be noted that (with some exceptions), researchers seem to argue for holistic design approaches, where the ship is treated as a system of systems. The way that an organization does business is colored by market dynamics, but also by the way that organization is managed. As noted in the literature, “behind any Sub-Standard ship there is a Sub-Standard owner or manager” (Soma, 2004, p. 13). Although LASH FIRE also applies a holistic perspective on fire safety, it may be asked how many shipping companies are ready to take in or realize fundamental changes to the design process, and to safety management.

Crewmembers report that only part of the working environment issues identified by crews ever become known to the land organization. In this context, there may be opportunities to introduce smaller, cheaper and more frequent working environment improvements. Interviews have shown that crewmembers will often engage in discussions with visiting system supplier representatives such as technicians, giving them feedback about system functionality and possible improvements. This and other interfaces could be explored further under the heading of safety and quality management, looking for ways to systematically transform operative experience into safety-enhancing design.

9.1.6 Future research

Future research propositions mainly target the two main design process stakeholders, i.e. How HCD principles in fire safety design could be pursued despite the many constraints that apply to both shipping companies and shipyards in the design and construction process.

ECONOMIC FRAMING OF FIRE SAFETY HF/E

- The many economic variables and transactions that affect fire safety design decisions have only been understood superficially and demands more research. One aspect of this issue is to go deeper into the question of project budgeting decisions.
- It has been noted that in some contexts, actions and interventions on behalf of the insurance client can serve to lower insurance costs, which is an incitement that could also be explored for the purposes of increasing ship workability.
- It was suggested in interviews that shipyard have few incentives to increase usability and ergonomics in their base products, but this issue will need further exploration in LASH FIRE. Developing fire safety holistically in “off-the-shelf” designs would target owners that prefer the cheapest ships i.e. the ones that may be in greatest need of design interventions. On the other hand, formulating a shipyard incentive for this is a serious challenge.
- A large amount of common variances in the ship design and construction has been identified and more research is needed to 1) understand how project variables impact end-product usability in fire safety related systems and environments and 2) if there are certain types of projects where the need for HCD integration in fire safety is particularly pressing.
- Could demonstrations of fire safety HF/E performance realistically be used to affect the shipping company’s insurance costs?

DESIGN SPECIFICATION & PROCESS

- More research is needed to operationalize fire safety HF/E for design purposes, i.e. an exhaustive representation of ship and equipment design impact on operative fire safety.
- To support organizational interventions, a timeline of the design and construction process should be constructed showing when, at the earliest, different aspects of fire safety HF/E can realistically be addressed, and what format that input needs to have to fit the recipient. This would be a way of applying HCD principles to the process itself, asking “what activities or information could be of use – and be used – under real project circumstances?”.
- Future research should study how incentives for HCD practices can be created among stakeholders that have little experience of working with Human Factors and ergonomics. In this context, it would also be interesting to go beyond the typical format of extensive HCD guidelines and experiment with alternative ways of bringing attention to human-centered design practice. The Lloyd’s Register whitepaper (2014) describes a maturity model for the introduction of HCD, and such a model could be used to investigate what the simplest, easiest steps could be towards improved fire safety HF/E, that are still effective and can demonstrate the practical use of HCD.
- Ship design carries on well into the building phase and those designs may severely impact usability and ergonomics. Although many aspects of the design cannot be altered at this stage, many others can be. Based on this premise, future studies should investigate ways of supporting the Site Team in their on-site controls and negotiations. One concrete set of issues that needs to be explored are the actual practices and effectiveness of on-site 3d model reviews, and to what extent they actually lend themselves to scrutinizing fire safety HF/E. The use of 3d models for design review could create new opportunities for end-users outside of the site team to contribute, something that could alleviate potential site team bias.
- This study has not provided conclusive data on whether design firms or manufacturers could provide more leverage on the main stakeholders in matters of fire safety HF/E. One particularly interesting issue is whether either of them could contribute to more unified, well-integrated designs.

FIRE SAFETY HF/E, VERIFICATION AND VALIDATION

- How can fire safety HF/E be introduced in design guidance, in a way that promotes effective implementation (e.g. with respect to project economics and organizational maturity)? This research should acknowledge experience from previous attempts to introduce human-centered principles in ship design and that so far, uptake has been limited (van der Merwe, 2015)
- How can the effects of fire safety HF/E issues (or the benefits of interventions) be represented in a way that the industry accepts, i.e. that can be used as a basis for regulatory decision-making?
- How should fire safety HCD regulatory/design demands be formulated in order to maximize both effectiveness and auditability?
- How can regulation support effective design integration in a market characterized by cost-minimization and fragmentation among system components (e.g. from different suppliers)?

- One topic that has only been touched upon very briefly in this study is the potential inclusion of work-related issues into early-stage project risk analyses. For fire safety, delays in the detection and response sequence is a considerable risk.

SAFETY & QUALITY MANAGEMENT

- There is a need of studies showing whether safety and quality management within the shipping company could be used to systematically turn operative experience into safety-enhancing design propositions. Over the years, a ship will go through numerous smaller design changes and system updates that can undermine usability and ergonomics, and this development could possibly be tackled through design management. Given that many shipping companies maintain their own base design, those could be a natural target for between-project design iteration.
- Laying the groundwork for user-informed design during daily operations could also make it possible for more crewmembers to contribute. One possibility is to explore methods for user involvement and design feedback that can be realized on ships in operation, where crews are actually located. It is possible that the growing area of 3d modelling could facilitate this.

9.2 Recommendations for fire alarm system interface design

Main authors of the chapter: Torgeir Kolstø Haavik, NSR; Brit-Eli Danielsen, NSR

In this section we first discuss the findings in terms of integration and standardisation, respectively. We do so by drawing on theoretical perspectives on HF design. Thereafter, we draw some implications for LASH FIRE Actions 7-B and 7-C.

Recommendations for design are grouped into the themes of integration and standardisation.

9.2.1 Integration of information means integrated systems

While the point of departure for improving fire detection system interface design in ro-ro ships is that alarm panels are treated as “stand-alone” systems, in the sense that these panels are designed with the exclusive aim to support fire management, there are clear indications that the user needs suggest more integrated concepts, and more graphical concepts. While systems integration in combination with digitalisation has had its wave in other industries – in particular this has recently been visible in the wave of Integrated operations in the petroleum industry (see e.g. Albrechtsen and Besnard (2013); Haavik (2013); Rosendahl and Hepsø (2013)), integration always comes at a price. Integration necessarily involves compromises, since specific solutions for specific tasks may sometimes have to give way to solutions that work across different tasks. On example could be the flexibility needed for placement of cargo for practical and logistical reasons, and how this can be difficult to harmonise with the need for compliance and predictability if the cargo manifest should be integrated into the same information system that a fire management system to be used actively in fire management situations. We have in this work not addressed the specific trade-offs necessary for integrated solutions to work satisfactory – but necessarily significantly better than existing solutions – but the findings both from earlier studies and the present project support a preliminary conclusion that further developments of alarm panel interface design should be seen in conjunction with an explicated need to gather also a range of non-fire specific information into a consolidated system.

New information types and action possibilities that the bridge officers would like to see in an integrated ship management system include cargo information, cameras and ballast management, in addition to information types and action possibilities that are directly related to fire management, but that are not today included in alarm panels, such as drencher information and management, location-specific temperature readings and fire-door management.

The needs reported from the users for a more integrated and graphical system find resonance in the design literature. Minimizing the information access cost, the proximity compatibility principle, the principle of pictorial realism, replace memory with visual information: knowledge in the world, and principle of consistency (Wickens et al., 1998) are all principles that support system integration *in general*. More specifically related to the maritime bridge management, the need for holistic alarm management (Merwe, 2016), grouping of functions (Vu & Lützhöft, 2018), consistent user interfaces (Nordby et al., 2019) and so on support that information and management systems that integrate fire and non-fire specific issues have significant advantages. Advantages include both the easy access to relevant/important information without having to move around on the bridge and search for different sources – something which may take considerable time – and the opportunity to interact and familiarise with a fire management system frequently although no fire situation is ongoing.

In practice, integrating the fire alarm panel into a larger information management system implies an important decision: to merge the efforts in this project's *Action 7-A Fire alarm panel* and *7-C Fire resource management centre* into one integrated system.

In the development of such an integrated, digital fire management system it will be crucial to maximize value through integration, and to lose as little value as possible. We have already discussed that trade-offs in functionality and presentation are unavoidable. Another issue is the risk of throwing the baby out with the bath water when systems are fully digitalised. Although we have so far not dug deeply into the socio-material aspects of information and crisis management related to fire situations, there is reason to believe that also the material resources used today have organising effects that have not necessarily been fully understood or accounted for; for example, the practise of gathering around laminated GAs and using marker pens to organise the response, may have some influence and positive effects on the collaborative work that digital solutions not necessarily will mimic if they are not explicitly designed to do so. This is a theme that should be explored further in this project through more detailed crisis management work studies.

9.2.2 Standardisation and contextual adaptation – a need for both

Integrated solutions call for standardisation to reduce the level of complexity that else would arise when several heterogeneous systems are merged into one. At the same time, integration is in itself an act of standardisation, since the number of interfaces is reduced. It is a general impression from our studies that the degree of standardisation in the maritime industry is low. This comes into expression by the crews and in comparison, with other domains, such as aviation. The difference in standardisation of tools and work processes between the maritime and aviation domain is striking. The reasons for this are diverse – see e.g. Haavik, Kongsvik, Bye, Røyrvik, and Almklov (2017) – and some are to be found in the different stakeholder networks characterising the industries. Under any circumstance, both advices and trends point toward a higher degree of standardisation of tools and work processes.

The artefacts and supporting work processes that are to be developed for fire alarm panels and fire management should support follow up these advices and trends, and introduce solutions that are consistent in the use of graphics and vocabularies, that use data formats and interfaces that allow for communication with other systems, and that aspire for spreading to numerous ships regardless of operator, and diffuse into rules and regulations. As such one might find many similarities in ambition with the ongoing bridge innovation initiatives mentioned in Section 0.

At the same time, we know from many practice studies and volumes of research literature that standardisation alone has its limits in promoting safe and efficient work in safety-critical domains. If too restrictive, standardisation can even represent a threat to safety, as it reduces the leeway and adaptability that is so essential to resilience in operations. This is true both for standardisation of artefacts and their affordances, and standardisation of work processes through procedures; inherent to the resilience of safety-critical sociotechnical systems are their potential for variety and adaptability.

A large body of literature on resilience engineering argues for this as a generic insight (e.g. Hollnagel, Woods, & Leveson, 2006; Pettersen & Schulman, 2016), and it also comes explicitly into expression in Hollnagel's (2016) perspective on human factors design, where the acknowledgement of trade-offs and workarounds receive particular focus. The importance to facilitate for alternative uses and not lock usage pattern to one correct and safe form, is seemingly at odds with the need for standardisation. Also, Hollnagel's principle 'The minimal action rule', implying that actions that might lead to adverse outcomes should be difficult to do, and really dangerous things should be impossible to do, seemingly lends more support from a standardisation credo than from an adaptation credo. However, standardisation and adaptation should not he held against each other as competing solutions. When it comes to design, instead of representing two different choices, standardisation and adaptation must both answer to contextual considerations.

The standardization approach should be considered. What is to be standardized is one question, but then there is also the qualitative nature of standards – what aspects of design are standardized, at what level of abstraction, how is compliance measured, as well as whether standards in themselves should be adapted to user needs.

Hence, a future improved fire information and management system interface should operationalise thorough empirical insight *how the crew actually works in fire situations*; *what are the positive (and necessary) variabilities of the systems, and what are the absolute limits of adaptation*, and establish design criteria based on such a contextually based balance between standardisation and adaptation requirements.

9.2.3 Implications for Action 7-B and Action 7-C

The findings and discussion related to user needs and design requirements related to fire related information and alarm panel functional and interface design have some concrete implications for the future LASH FIRE work on fixed fire extinguishment system activation (Action 7-B) and Fire resource management centre FRMC (Action 7-C).

- An improved fire alarm panel should be integrated in the larger FRMC system, not only as a stand-alone system in this decision support environment, but as a technically, functionally and design-wise integrated information and management system. This information and management system should include core parameters and information types related to fire, but also other parameters and information types that have not traditionally been included in fire-specific systems.
- Improved activation procedures for fixed fire extinguishment systems for quicker activation should lend support from the FRMC. The results from our studies so far indicate that an FRMC information interface should be populated with information that is today often dispersed onto several digital and analogue surfaces, including easily understandable information on physical location of detectors, temperatures readings, camera streams and cargo manifests. This information is important in the decision-making process, and improved decision processes for activation should assume these FRMC functionalities. In addition, it must be explored whether activation of drencher and CO_2 systems should be possible from the FRMC – probably in addition to possibilities for manual activation from other locations (bridge/engine control room).

10 Conclusions

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The work behind D07.1 has been directed towards three topics, representing different abstraction layers of ship design:

1. How fire safety-related end-user needs and requirements are represented and treated in the ship design and construction process, and what barriers exist against increased use-centered design practices
2. How the integration of end-user needs in ship design is affected by regulation and the regulatory process
3. What design aspects should be considered in the development of new technical fire safety solutions within LASH FIRE, with an emphasis on fire alarm system interface design.

Studies have identified design process issues with regard to HCD introduction strategies, shipping company organizational practices, design process variance, project financing, project risk assessment, purchasing, forms of end-user involvement, site-team activities and support, shipyard base designs, change management, and shipping company market dynamics such as operational flexibility. Exploration of these issues will continue and form the base of future LASH FIRE organizational studies and development. This future work will serve to fulfil the LASH FIRE WP07 objective to increase the uptake of human-centered design for fire safety, and help to frame guidelines for improved fire detection system interface design, promoting intuitive operations and quick decision-making.

The regulatory analysis has showed that the current regulations and regulatory process combined with market and organizational conditions, have led to a focus on technical fire regulations. Usability and operational fire management are harder to audit and thus less complied with in the shipping companies. To meet the intentions of fire safety, one cannot ignore the design and operational phases.

A key objective in LASH FIRE WP07 is to suggest “improved design of tools, environments, methods and processes for critical operations in case of fire”. The user needs and requirements for alarm system design point towards design solutions that integrate an improved fire alarm panel interface with an information management solution, thus providing the fire resource management system (FRMC) with necessary resources for information access and actuation possibilities. Among the information types and actuation possibilities that should be considered to integrate into the FRMC system are location-specific temperature readings, cargo information, drencher information and management and fire-door management. A need for thorough considerations of the balance between solutions that ’standardise use and work processes’ and solutions that provide leeway for contextual adaptation are advised. Issues that should be further explored and considered in that respect are consistence in the use of graphics and vocabularies, and standardised data formats that allow other systems to connect, and sufficient affordance of systems to facilitate for sufficient flexibility in use. The findings in this report are recommended to be included in the early phase of design work and to be further developed as alarm panel and FRMC prototypes are developed. This to ensure contextually anchored user relevance.

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