Holistic Human Safety in the Design of Marine Operations Safety

Abstract

To avoid safety issues, current marine operations safety protocols follow only the work procedures and technical structures of systems that are provided by the operator; regardless, research continues to report safety issues related to cooperative work within marine operational systems. Thus, we use the concept of boundary object to analyze excerpts from a series of field notes and to discuss holistic human safety. We illustrate that human safety is only supported at the individual level of engineering community practices but does not address safety at a cooperative level between marine operations and other operations. At the individual level, human safety issues can be related to technical errors and failures in interaction and communication. This paper presents suggestions on how to make the work practices of marine engineers and marine operators visible within design processes, enabling them to collaborate with engineering designers and human factors engineers in the design of marine operations safety.

1. Introduction

In the maritime domain, research that focuses on the improvement of human safety is typically conducted by engineering designers. These designers use a systematic design approach (Pahl et al., 2007) to analyze and identify work situations from product and system design features. This approach includes a set of theories and methods that can identify essential problems, establish the functional structure of systems, search for solution principles, and combine them (Sadeghi et al., 2016). Marine engineers, engineering designers, and human factors engineers believe that human safety is consequently affected by technical systems (Kleiner et al., 2015). From this perspective, risks to human safety can be avoided through enhanced technologies and by training operators to follow appropriate work procedures for operations and the technical structures of systems. As an example, most marine engineers understand that human safety is impacted by marine operations. Safety can therefore be ensured by designing work procedures that adhere to national and international regulations (Det norske maskinistforbund, 2013). Marine engineers approach human safety by considering how to make work procedures suitable to every unique marine operation that marine operators encounter. Because it is an attribute that exists within technologies, engineering designers can secure human safety with advanced technologies (Sadeghi et al., 2015). Therefore, human safety can be measured through appropriate experimentation by human factors engineers (Lützhöft, 2004). Human factors engineers believe that human safety risks can be avoided by iterating upon enhanced technologies during design processes and by evaluating the interactions between the operators and interfaces of those technologies.

Thus, studies in maritime research have followed these approaches during attempts to solve human safety issues amongst marine operators and marine operational systems within cooperative work environments. These studies have used a variety of methods, such as marine operational systems to enable cooperative work, which have been developed with collective and individual computer systems, alike (Park et al., 2004). However, existing literature (Aas, 2010) has continued to report human error as a causal or contributing factor in 60% to 90% of all accidents (Baker and McCafferty, 2005). Of these, approximately 50% of maritime accidents have been the result of human errors that existed outside of the context of technical systems. In addition, Baker and McCafferty (2005) revealed that 30% of marine safety incidents resulted from human failure to avoid accidents during cooperative work.

The nature of human safety in marine operations safety is complex (Kongsberg, 2016). Marine operations are highly cooperative and require multiple marine operators to use marine operational systems within cooperative and socio-technical environments (Hepsø, 1997). When marine operators use marine operational systems, human safety issues do not always arise at the individual level. Rather, these issues can emerge from cooperative work that takes place between marine operators and marine operational systems (Forskningsrådet, 2012). In design research, researchers have argued that when cooperative work is considered to be a part of the social fabric of design, it is often overlooked during the design of cooperative operations technology (Manzini, 2015). As such, we believe that understanding safety in the context of individual engineering work, like the design of safety features for an engineering system to support holistic human safety within cooperative operations, can lead to inadequate engineering work in the maritime domain.

Although many researchers have called for holistic engineering work practices to support in situ work and socio-technical innovations, few studies have focused on methods that can merge social and technological characteristics in order to solve engineering problems. For example, Petersen and Buch (2016) explored how the user-experience approach synthesized engineering practices at a car manufacturer by enabling certain engineering methodologies to work across various engineering organizations. However, their study failed to explain how users could participate in engineering work to make their efforts visible. Rather, Petersen and Buch focused primarily on engineers who estimated car buyer’s purchasing requirements so that they could restructure engineering organizations.

By contrast, we argue that in current marine operational systems, the in-situ work practices of marine operators and marine engineers are largely invisible because they are typically unobserved (Star and Strauss, 1999). In order to improve and extend marine operational systems, and to address the ecology of marine operations safety, we intend to make this work visible. To gain this new understanding of human safety in engineering work, we use the concept of boundary object, which according to Star and Griesemer (1989), is robust enough to allow researchers of design research to collaborate with other engineering practices and to analyze and investigate human safety. As a boundary object, human safety requires marine operators, marine engineers, design researchers, and engineering designers to address the safety operations of every stage of marine operation. This can enable engineering designers and design researchers to shape marine operational systems within the context of marine operators and their cooperative work.

In addition, if we treat human safety as a robust feature that permits marine engineers, design engineers, and human factors engineers to practice marine technology at the individual level of their different communities, human safety can be supported through the use of enhanced technical systems (Backalov et al., 2016) and institutional work procedures. In addition, if human safety can be made flexible, it can be supported by enriching the social meaning of engineering practices from a holistic human safety perspective within cooperative work environments, which can in turn allow marine operators to vocalize their opinions about the in- situ cooperative work practices of marine operations to marine engineers and increase their ability to perform efficient work procedures. This paper's definition of holistic human safety therefore refers to good cooperation amongst various engineering communities during the design of marine operations safety protocols that support cooperative marine operators.

The paper's research questions include the following: what type of marine operational systems can provide holistic support to human safety; what methods can be used to design these systems; and the involvement of what types of knowledge from the different engineering communities—marine engineering, design research, engineering design, and human factors engineering—can be used to support marine operations safety? In addition, the paper will be structured as follows: section 2 will discuss the definition of the word *safety* and the current understanding of human safety within the maritime domain; section 3 will introduce the empirical setting; section 4 will present the data collection and methods that are used in this paper; and section 5 will use a boundary object to illustrate how marine operational systems and human safety are built within field studies.

In order to make the work involved in marine operations visible during the design of marine operations safety, the paper will also review the processes that demand cooperation between design researchers and design, maritime, and human factors engineers. Using analyses of earlier field work that was conducted at sea, this paper will argue for the importance of integrating the work of marine operators and marine engineers into common engineering practices, such as designing operational systems and ensuring ecology within marine operations safety. Finally, section 7 will explore methods that can enrich engineering work so that it can support a variety of marine operations. The paper will then conclude that designers and engineers will need to use the outcomes of field work to drive bottom-up socio-technical innovations that can force the evolution of both social and technical practices and support human safety in cooperative work environments, such as marine operations.

2. What is safety and human safety in the maritime domain?

Despite the common interest in safety and human safety in the maritime domain, definitions for both remain insufficient. It should therefore be made clear that this paper’s position on human safety is different than most engineering studies by comparing with safety and human safety in the maritime domain.

According to the National Aeronautics and Space Administration (NASA, 2008), safety focuses exclusively on physical rather than functional consequences. In terms of product safety, a product is considered to be safe when it does not result in death, injury, occupational illness, damage to the environment, and damage to, or loss of, equipment or property. By comparison, research related to marine engineering, engineering design, and human factors engineering considers human safety to be a part of the machinery safety process (Khan et al., 2015), wherein machinery control systems are modeled to guard against predictable safety problems through scheduled testing and integrated engineering design procedures.

However, safety in the maritime domain includes two additional categories: system safety and human safety (Sadeghi et al., 2016). System safety (Akeel and Bell, 2013) involves the application of engineering and management criteria, principles, and techniques in order to optimize safety within the constraints of time, cost, and operational effectiveness throughout all phases of a system's lifecycle. System safety is to safety as systems engineering is to engineering (Sadeghi et al., 2015). In engineering design, system safety is only addressed to improve engineering design (Sadeghi et al., 2015) and to determine ways in which systems can be used without risk (Rausand and Utne, 2009).

Human safety is impacted by system safety (Akeel and Bell, 2013) and is determined by safe human engagement with technology. Human safety is also related to the non-functioning part of a system, or the part of a system that follows certain conditions for a given amount of time. Human factors engineers analyze human safety in terms of systems use and behavior. This approach is different for marine engineers and engineering designers, who understand that human safety is connected to technology and work procedures (Bal et al., 2015). Human factors engineers also look at the issue to optimize routing and scheduling on behalf of workers' health and safety, with a focus on psychosocial factors and musculoskeletal disorders (Lützhöft, 2004). Recent research has determined that since organizational cultures can influence the choices of individuals, safety is also affected by human and organizational factors (Chauvin et al., 2013; International Atomic Energy Agency, 2013). Some of these organizational factors include resource management, organizational climate, organizational process, and statutory requirements. Every one of these factors affects supervisory actions, as well as the conditions and unsafe actions of marine operators. Understanding organizational factors can aid in the protection of human safety at an organizational level. Regardless, the natural cooperation of marine operators within work environments might be dismissed upon investigation of human safety issues from a holistic perspective. As such, this paper aims to illustrate how field work can be used to drive bottom-up social and technical innovations between the work-as-imagined and work-as-done mantras of the maritime domain. In terms of top-down risk management, organizational factors exist outside of the scope of this paper (Det Norske Veritas, 2001; Palola, 2015).

By contrast, human safety in the maritime domain is multifaceted. First, safety occurs within the context of marine operations, such as through the resolution of mechanical issues within technical systems (Rausand and Utne, 2009). Second, because human-machine interactions are led by institutions, there are both physical- and software-related consequences to safety (Backalov et al., 2016). Therefore, human safety can be considered to be dependent on the safety of a ship's stability (Backalov et al., 2016). As an example, human safety may be considered to be paramount during investigations of a ship's structural requirements for complete control. Human safety can also be used to measure the probability for select operations, such as navigation and offshore activities, and to test marine operators in the selection of certain criteria, such as loading conditions and wave, vessel, and seaway geometry (Stanton, 2014).

In the current maritime domain, human safety involves reliably backing up internal and external devices (Dunn, 2003) to ensure safety within systems development. From this perspective, marine engineers primarily focus on analyzing safety regulations and designing work procedures so that individual marine operators are capable of using technical systems. To some extent, human safety is dismissed within cooperative work. In addition, human factors engineers and engineering designers contribute to human safety in marine operations as a presumptive condition for the enhancement of marine safety. Unfortunately, while these presumptive conditions dominate natural work situations, we believe they are inadequate because they are limited in their scope of safety precautions. Moreover, a marine operator's primary role is to protect systems by avoiding operational human risk. We argue that human safety should involve performance safety rather than risk prevention (Wachter and Yorio, 2014). Human safety does not function in an isolated context that engineers can explain by communicating within their own fields (Faye, 2009).

As an engineering field, the current maritime domain involves straightforward problem solving (Faye, 2009) for human safety issues without any in-depth study of the in-situ work practices of end-users (Lurås, 2016). We argue that this type of problem-solving solution does not lead to a better understanding of operator performance within the field of engineering (Kwee-Meier et al., 2016). Rather, it only helps when operations and machines are fit for use in individual work practices. In marine operations, human safety should involve more than individual circumstances. It should instead adopt a holistic view of cooperation amongst domain professionals (Daniellou et al., 2011).

Goodwin (1994) argued that professionals are people who have the ability to highlight and respond to the work situations that unfold before them in their fields. These individuals develop knowledge from their work environments, their previous experiences, and the theories that underlie their professional educations (Jung et al., 2010). It is therefore important that engineering practices in the maritime domain relate to the context of human safety (Kwee-Meier et al., 2016) so that the in-situ work practices within cooperative work environments can be visualized. This can bridge the gap between the work-as-imagined and work-as-done mantras of the maritime domain. As an example, several researchers have suggested that performance adjustments to engineering practices are necessary, as most people change their work output to match specific situations. In these cases, performance variability is inevitable, ubiquitous, and necessary in a variety of fields, such as healthcare (Braithwaite et al., 2017; Wears et al., 2014), aviation, and nuclear power (Hollnagel, 1993).

Failure to recognize the nature of work practices can lead to oversimplified, incomplete, and outdated knowledge about work circumstances and thus result in the poor performance of certain engineered systems (Braithwaite et al., 2017). As such, the visualization of in-situ work practices within cooperative work environments can support human safety as an explicit, discussable, transferrable, and growable element of engineering work. Engineering communities need to rethink human safety's classification as a boundary object for socio-technical innovation by bringing together the different engineering practices that shape marine operational systems. Engineering communities should also encourage in-situ engineering work by allowing engineers to use the knowledge that is inherent to their individual communities during the overall design of safety operations.

3. The empirical setting: the marine operational systems on a ship's bridge

This paper's empirical setting was the marine operational systems of a ship's bridge (see Figure 1). The field study was conducted on the bridge of an offshore supply vessel, wherein operators used marine operational systems to complete offshore tasks.

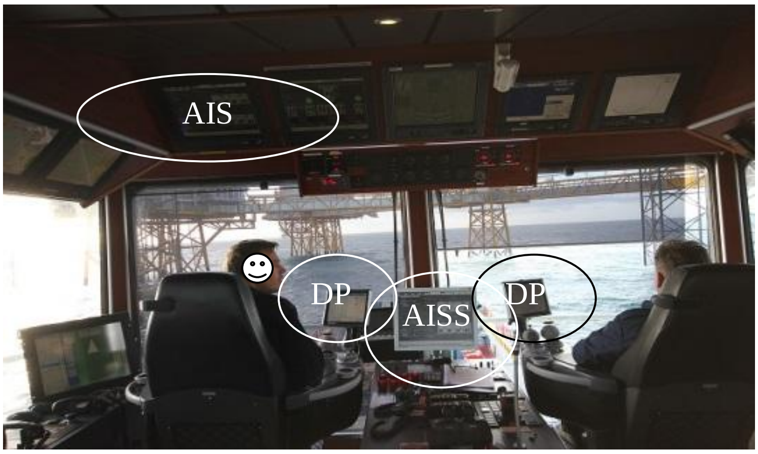

Figure 1: Marine operational systems on the ship's bridge (AIS – automation integrated systems, DP – dynamic positioning systems)

The crew on deck, in addition to the communications that took place between the offshore supply vessel and the oil platform, were also considered to be part of the research area. Information that was useful to the maritime operators were displayed via 18 displays and physical operational levers (see Figure 1). Dynamic positioning systems were placed in two screens in front of the marine operators' chairs. The automatic integrated systems (AIS) included two screens in front of and a screen in between the two marine operators' chairs. We chose AIS and dynamic positioning (DP) systems because we believe that DP systems that are associated with AIS and other marine operational systems represent basic functionality for most simple marine operations and services. AIS are programed to monitor and provide alerts for the storage of liquid materials in containers that rest under a ship's bridge. These systems significantly increase a ship's reliability (Automation Heinzmann, 2017), detect process malfunctions faster, and reduce operators' intervention-times during marine services (Transportation Research Board, 2003). As an example, marine operators could use AIS to provide drilling-mud and -water to the oil platform while simultaneously establishing the balance of a vessel (Pan, 2016). Thus, this study focuses on the work of two teams of marine operators who used both marine operational systems (AIS and DP systems) every six hours. Each time record included two marine operators who belonged to a single team. Sailors on deck who assisted the marine operators on the ship's bridge were also involved in this study.

4. Method

The work presented here is part of a larger project that examines marine operations. The aim of this project is to criticize the existing design of marine operational systems, move beyond these criticisms of current marine technologies in a constructive manner, and attempt to influence specific features of the creation and implementation of marine operations safety. After receiving approved ethical consent from the Norwegian Centre for Research Data, the study began in the fall of 2013. It is currently nearing completion. It is an empirical workplace study that can be divided into three phases with different but highly interlinked focuses. Since the focuses of many of the activities overlap so that the parts of each phase influence the findings of other phases, it is impossible to distinguish each research activity by phases. Therefore, the three phases are as follows:

1. The investigation of marine operational systems with a focus on cooperative work within group activities.
2. The development of a design-based approach to marine operational systems, which in turn supports cooperative work between marine operators and design engineers during the engineering design process.
3. An investigation in the design of marine operations safety in order to shape a developmental environment for the design of marine operational systems with a focus on safety regulations and the rules of work procedures.

While this paper focuses on the third phase, empirical observations from all three parts of the study contribute to its empirical foundation. In the first two phases, the focus was to investigate the problems and challenges in evaluating marine operational systems that became present during research at sea with marine operators. One of the main findings from the first phase was that the evaluation of interactions between marine operators and marine operational systems inadequately represented safety concerns at sea. In addition, the study determined that current design and evaluative methods dismiss the safety issues of marine operators’ work practices at the cooperative level. Moreover, phase two used a network-based approach to investigate systems development with a focus on cooperative work during the engineering design process. In other words, the design of marine operational systems that support cooperative safety operations should involve design researchers and engineering designers by integrating the in-situ work practices of marine operators into the design of engineering systems.

The empirical study presented in this paper relates to the first and second phase. It is also comprised of an in-depth analysis of the safety issues related to work practices and is embedded within a larger picture of how marine operations safety is designed. We seek to use a boundary object as an analytical lens. This object exists in various fields of engineering during the design of marine operational systems that account for human safety. By placing each engineering community's practices under this analytical lens, a conceptual framework that uses the work practices of every engineering field in the maritime domain can be organized around the design of marine operational systems and provide knowledge that drives marine operational systems to support marine operations safety.

The primary data that this paper uses are comprised of various research activities that contribute to the understanding of marine operators' work practices within marine operational systems. The primary activities include observations of the work practices, informal and formal interviews with marine operators, and analyses of the various artifacts in use. The observations of work practices took place during six sets of offshore trips. Each set of trips included roughly 14 observations that lasted between 7 and 11 days long from January to May in 2015, wherein the primary author of this paper observed the work practices and marine operational systems on the ship's bridge while conducting formal and informal interviews with the marine operators about their work. These observations focused primarily on how marine operators cooperated with each other and used the marine operational systems to monitor tasks that required a certain degree of safety, such as activities that took place above deck. The interviews were conducted when safety issues or unusual operations (e.g., work outside of planned work procedures) occurred. In this paper, the field notes that were taken during the offshore trips are represented below in the form of a series of vignettes.

These notes can be used to analyze how the consideration of human safety in work practices can allow design researchers to use a boundary object as an analytical lens, which in turn can be used to evaluate how human safety can be identified and managed in every engineering community that uses non-cooperative practices during marine operations. However, human safety requires a cooperative and holistic view of marine operations that enables the incorporation of different engineering communities to design marine operations safety protocols that are suitable to those who conduct field work. The following is an excerpt from the field notes that were taken by this paper's primary author.

> The first officer and the captain sit in front of the marine operational systems interface. The first officer checks all the paper forms before he starts DP operations. His colleague, the captain, helps him check the weather information using separate office systems. It is clear that these office systems are not part of marine operational systems and are located in a different place. The first officer notes weather data on his paper forms as the captain speaks out. These paper forms are pre-prepared in order to document important information, such as DP operations, during marine operations. These are requests from the shipping company that concern safety issues. For example, the paper forms need to log dates, time, place, weather information, and who is on duty during marine operations. In specific paper form, such as the DP checklist form, information about sea wave, wind, and engine status also need to be documented. All these forms will be sent back to the shipping company time and again.
>
> The first officer positions the vessel, approaching the "Bergen" platform (Bergen is a pseudonym for the platform's name). After successfully positioning the vessel at the correct place, he stops and holds the vessel's position. The captain picks up the communication device and dials a number to call Bergen. He asks Bergen if the crane operator is ready to help adjust the vessel's position. Then he calls to the sailors on deck to check the position of the crane.
>
> The crane on the oil platform is too high for the first officer even though the crane operator tries to put down a rig. The first officer's sight line is also blocked by the frame of the window on the ship's bridge. He has to stand up to observe where the crane is because it is difficult for the sailors on deck to accurately explain the position of the crane. Simultaneously, he hands over DP operations to the captain who can help to hold and adjust the position of the vessel. The captain positions the vessel at the right place with the guidance of the first officer and the sailor on deck. After DP operations, the first officer prepares to supply Bergen. He confirms the work tasks that are documented on the forms from the shipping company. Then he orders the sailors on deck and the crane operator on Bergen to connect the hose between Bergen and the offshore vessel. After the hose is connected, he turns on the service to pump mud type I from the offshore vessel to

> Bergen. At the same time, the captain asks Bergen to lower the containers that will be brought back onshore.
>
> When lowering the containers, the captain has to guide the sailor on deck to position the containers at specific locations. This is because these marine service operations also change the balance of the vessel. Mud type I also carries weight. Suddenly, Bergen tells the first officer to stop delivery of the mud supplement. Instead, Bergen asks for drilling mud type VI and tells the first officer that a change form has already been sent to the office systems. This change is not planned. The captain, therefore, has to stop guiding the sailors on deck and move to the office systems' location. The captain asks the first officer to hold the vessel's position and guide the sailors on deck to lower the containers for him. The captain turns on the computer and printer to print out the request from Bergen for checking and approval.
>
> Although he tries to guide the sailors on deck to position the container, he fails to communicate with them as his workload at this moment makes communication impossible. He cannot hold the vessel, guide the sailors on deck, and monitor the marine services all at once. In addition, the marine service system has an error—one pump is not working. He is aware that this may cause trouble even though he intends to ignore it. Suddenly, both the engine room engineers and the chief call the bridge to draw attention to the balance of the vessel. The first officer stops the marine services but is only able to maintain the position of the vessel and its balance by shifting the mud below deck from one side to the other. He does not know how much mud should be shifted, so he makes his best estimate [Field notes in 2015].

5. Boundary objects

Star and Griesemer (1989) introduced the concept of boundary object to facilitate knowledge into how various actors who are involved in a task can cooperate on a project in spite of their different backgrounds and varied, often conflicting interests. They gave an example that the work of amateurs, professionals, administrators, and others connected to the museum of Vertebrate Zoology at the University of California, Berkeley had *n*-ways to translate their own knowledge of an object. According to Star and Griesemer, "a boundary object is any object that is part of multiple social worlds and facilitates communication between them; it has a different identity in each social world that it inhabits." Boundary objects embody a number of perspectives and are used by multiple groups to serve their own purposes and to address their own concerns while facilitating translation and understanding between several groups at the same time. Boundary objects do not equate to agreement but rather to interpretive flexibility (Trompette and Vinck, 2010). As Star and Griesemer (1989) asserted, "boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. Like a blackboard, a boundary object 'sits in the middle' of a group of actors with divergent viewpoints."

When bringing boundary objects into practice, Bowker and Star (2000) focused on ways in which to classify them according to different communities of practice or social worlds. Certain objects can become naturalized and routinely used by members of a community so that their function becomes transparent and they are taken for granted by members of that community (Bowker and Star, 2000). Boundary objects can therefore be understood as objects that are not fully naturalized by any one community of practice. Instead, they arise from situations where "two or more differently naturalized classification systems collide" (Vederhus and Pan, 2016). Thus, boundary objects aid in the negotiation of areas of overlap between multiple communities and are created from within field studies so that they may build and structure an ecology wherein each community can find its bearings and make headway (Trompette and Vinck, 2010).

Every engineering community understands human safety, and the design of marine operational systems in particular, differently. While human safety is robustly considered by each engineering community, flexibility, as a holistic feature of marine operations safety at large, is frequently misunderstood. For example, the traditional routes for designing safety marine operations (Vederhus and Pan, 2016) involve national and international regulations and the design of work procedures by marine engineers in order to train marine operators according to their experiences (e.g., their personal communications with marine engineers). Following this, engineering designers and human factors engineers work on constructing marine operational systems and their associated equipment so that they may place them within vessels. Work procedures can change depending on the training processes that are required to operate marine operational systems. However, while marine operators are trained to follow these work procedures with regards to safety concerns, they do not provide feedback on the design of marine operational systems or their application within marine operation safety during in-situ work practices. Thus, when safety issues or unusual work procedures present themselves during cooperative work practices, there exists a division between operators, human factors engineers, marine engineers, and engineering designers and their ability to cooperate on a specific design. In other words, marine engineers, engineering designers, and human factors engineers loosely contribute in the design of marine operation safety and only address safety issues within their individual communities of practice (see Figure 2).

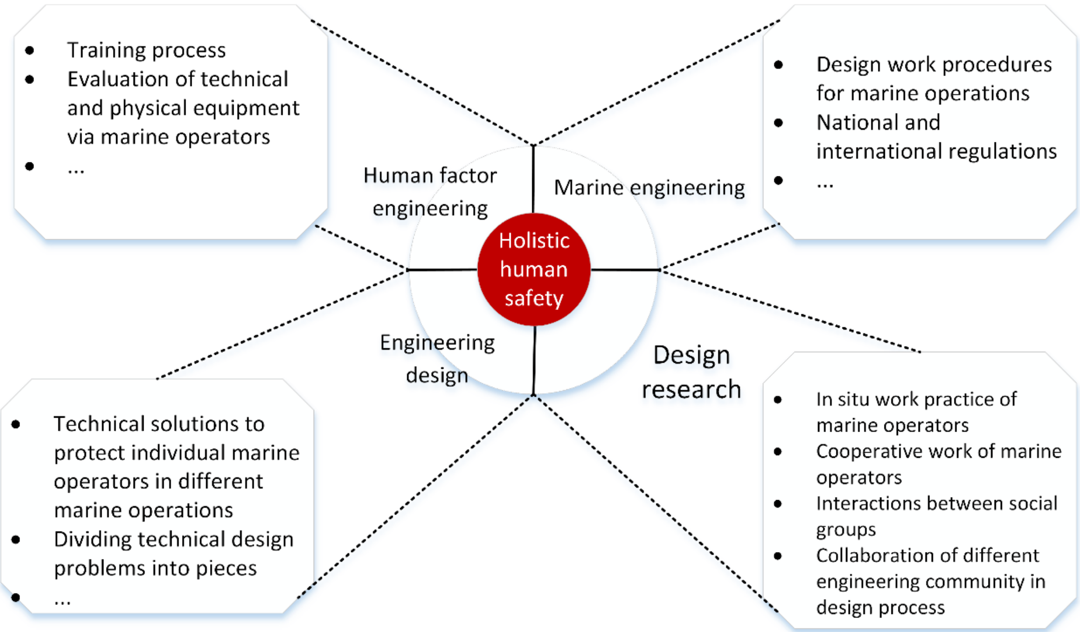

Figure 2: Human safety as a boundary object in marine operations.

In addition, the construction processes of marine operational systems follow the traditional developmental processes of systems engineering (Rigo et al., 2010). These can include the use of stakeholder wishes and requirements, without considering the in-situ work practices of marine operators, by design engineers (Vederhus and Pan, 2016). Following this, design engineers write these opinions and desires on small pieces of paper, stick them on a wall, and wait for their approval by human factors engineers. We believe that the in-situ cooperative work practices of marine operators are usually viewed as social factors that can be automatically excluded during developmental processes.

It is difficult to bridge the gap between the social and engineering approaches to the developmental process (Dourish, 2006). Human safety does not fall easily into the categories of engineering design, marine engineering, or human factors engineering. Human safety is in itself an object that can facilitate internal group interactions in a positive way (Trompette and Vinck, 2010). The elements of human safety are closely related to the competencies of the different engineering fields (Trompette and Vinck, 2010). Therefore, human safety is represented in the different engineering communities by the technical errors that present themselves within marine operational systems (Backalov et al., 2016), interaction failures between marine operators and marine operational systems (Stanton, 2014), and communication faults (Pyne and Koester, 2005) that occur during maritime tasks. However, when a boundary object is applied as an analytical tool to evaluate human safety, it is important to note that human safety is also a holistic artifact that requires design researchers to incorporate the approaches of different engineering fields in the design of marine operations safety at large.

While cooperative work between end users is a factor that has been largely dismissed in day-to-day engineering practices, Manzini (2015) argued that it remains an important issue. To develop socio-technical systems that support cooperative work, experts must co-design these systems using bottom-up processes that combine social and technological innovations. The work of marine operators and marine engineers needs to become visible. Because marine operations are unique and each operation has its own work procedure, they must be represented with field notes so that engineering designers can better understand the in-situ work practices of marine operators. In addition, marine engineers should adjust work procedures and make the effort to inform engineering designers about manners of safety. Thus, boundary objects are useful analytical tools that can bring different engineering practices together while illustrating how cooperative operations can be framed as socio-technical systems that support holistic human safety.

Below, we use a boundary object to analyze human safety within a series of vignettes, investigating how different engineering practices can contribute to incompatible approaches to safety within cooperative marine operations. We then establish human safety as a boundary object to inform the design of marine operational systems and affirm that these design processes require cooperation between marine engineers, marine operators, engineering designers, and human factors engineers.

6. **Human safety issues in cooperative marine operations**

DP operations are typically designed by an operator so that they adhere to the work procedures that are necessary to run the DP systems. However, according to the first officer's field work, these work procedures were expanded during the events that we recorded aboard the offshore vessel. DP operations and initial cooperative work involve the captain, the crane operator, and the sailors on deck and are comprised of paper forms, the communication systems, and the DP systems (see Figure 3). When positioning the vessel, the first officer is unable to communicate with the crane operator on the oil platform. It is therefore unsafe for the first officer to hand over his work to the captain, who operates the DP systems directly. In addition, when the captain initiates DP operations, the DP systems lack updated weather information. The captain is also unable to check the office systems since they are in a different location. However, safety issues typically do not arise during this type of field work because the first officer is tasked with observing the crane for the captain. In addition, he communicates with both the captain and the sailors on deck and checks for current weather data on the captain's behalf.

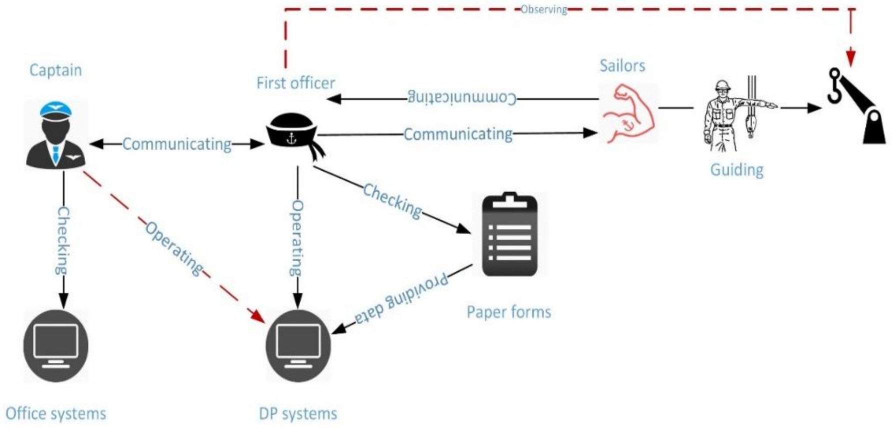

Figure 3: DP operations

Once the vessel reached the correct position, the first officer initiated the next marine operation, providing mud type I to the platform. In the meantime, the captain began guiding the sailors on deck to lower the containers. Following this, DP operations were joined with another set of marine service operations (see Figure 4). The captain and first officer participated in both teams and used their knowledge of each operation type to inform the other participants.

When the ship received a call from the platform to stop delivering mud type I, operations had to make a change to enable the captain to sign and approve the change forms using the office systems, which were not synchronized with any portable devices at the captain's disposal. Thus, the captain needed to return to his office area to collect the email.

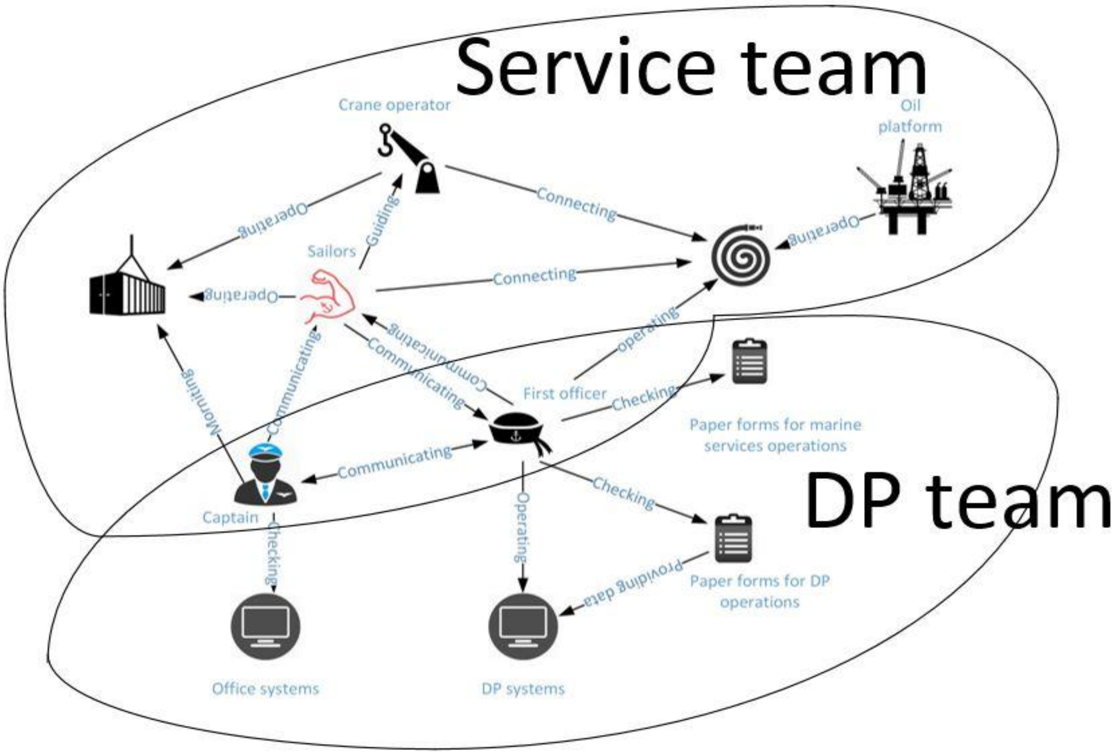

Figure 4: Marine services and DP operations

The first officer maintained the position of the vessel while acquiring the information he needed through the communications systems so that he could continue delivery of mud type I. He was also responsible for maintaining the vessel's balance through both the marine services and the DP systems. When a change request from the oil platform required a change from mud type I to VI, there was a lack of information. A lack of cooperative work between marine operators can raise safety issues that include technical errors, interaction failures, and communication faults. In turn, these can result in the destabilization of the vessel.

The first human safety issue that occurred was a technical error within the marine service systems when one of the pumps stopped working. Nevertheless, the first officer continued his duties until the mud type was changed:

> The pump does not work for two days. I have to continue my work even though there is something wrong. For a little work, I do not think it will matter. I do not

> know what will happen if we have to work with a platform for a long time to provide mud.

While the first officer was aware of an error, he chose to ignore it. The captain went to the location of the office systems because the first officer was unable to change from one mud type to another without both the captain's and the shipping company's authority. Thus, the work of guiding and monitoring the containers shifted from the captain to the first officer, making the safety situation worse. It was an impossible task because the first officer could not communicate directly with the crane operator to lift the containers. In addition, the first officer and the captain had no information about the weight of the containers. While the crane operator knew this information, limited communication prevented the marine operators from gaining access to this information beforehand.

When the captain left the marine service operations to check the office systems, the first officer had no way of updating his work with new information. In addition, he was unable to stop his work on DP or marine services or in his guiding and monitoring of the containers. Therefore, he continued work on these operations until he was no longer able to proceed. This paper's primary author interviewed both the first officer and the captain simultaneously after the shift in work duties that had come as result of the request to change mud type. When asked about the relationship between work capabilities and the safety issue of balancing the vessel, the captain responded as follows:

> No information can alert us to possible safety issues if I [the captain] leave my work to him [the first officer]. Because if I have to get approval from the company, I cannot wait for a long time; you know, we have already waited here for a day. I need to save time for more operations. I just hand over my work for a minute to him [the first officer]. I assume everything is good because this imbalance issue does not happen often. This time [the imbalance issue] may be because the containers are overweight.

The primary author then asked if they were aware of the weight of those containers and if it was possible to gain access to that information beforehand. Both of them answered no. They only had access to a document that listed basic information about the containers, such as company names. The same applied to the work procedures for marine service operations. They were not allowed to update paper forms for marine services due to a number of regulations that had been set in place by the oil company. Although the office systems received updates, this information was not shared with the first officer. As the captain reported:

> The work plan for marine service operations is revised by the shipping company and the oil company. However, the work plan may be revised again during marine operations at sea. We have no idea when it will be changed. Also, I cannot check it on my operational systems even though I have some screens here [in the marine operational area]. When I sit here to work on service operations with the first officer, I have to stop from time to time to see if there is a request from the oil company …. This is quite annoying. You already saw, but I have to do it ….

After he had taken responsibility for monitoring and guiding the containers, the first officer knew when he needed to communicate with the sailors on deck. As he was unaware of how much the container weighed, his guidance to the sailors on deck was incomplete. The primary author followed up with questions on this issue by asking the first officer if he had experience in handling two operations at the same time. The purpose of this question was to determine if the first officer lacked experience or if inexperience was even an issue. The first officer said:

> I have seven years' experience on marine operations, mainly working on the bridge. I think this is not the first time I have seen imbalance issues. I communicate with the sailors, but I am unable to tell them how to guide the crane to place it in a specific place. Do you remember that there is an error in the system? That is okay even though it is an error. However, most importantly, I lack information about which side of the vessel is light, for example. We have different types of muds, and they have different densities. I cannot get this information from my DP and service systems. Therefore, I just use my experience with the vessel. If the left side is high, then I give instructions to lower the left side of the vessel, for example. I guide the sailors using my experience.

The sailors on deck confirmed this. The author asked many of the sailors how they communicated with the crane operators on the oil platform about container information. One of those sailors responded:

> We have a communication system with the crane operator—gestures. However, we do not have any information about the containers. Our work is to guide the crane operator to place the container at the right place on deck. Gestures do not tell us anything about the weight [of a container].

The primary author then referred back to the captain and the first officer to inquire about the correct locations for the containers. The captain said:

> I usually have a pre-planned form marked with different colors. I use that form to guide sailors on deck as to where to place a container. However, it is just a paper with some colors. It does not help much to balance the vessel. Because it does not always match the information regarding what types of mud we have. Those two things go hand-in-hand and must work together. That is a mathematical problem. Well, it is in my experience.

Using the above analysis, we discovered safety issue that can occur during operational systems cooperation. When two operations focus solely on one piece of a scheduled work procedure within marine operational systems, there are fewer safety issues because marine operators are aware of the complexity of marine operations and are trained to react properly to safety issues that occur during marine operations. In the above example, for instance, the first officer would have been able to safely run DP operations and provide mud to the platform. It should be noted that marine operators are trained to perform these solo operations via an interview that is administered on board every two years.

However, imbalance issues (see Figure 5) occur when cooperative work fails to proceed smoothly. While there may be fewer technical errors in marine operational systems, and fewer problems when marine operators interact with marine operational systems on an individual basis, human safety problems can arise when these pieces of distinct work are put together. In the above example, for instance, the captain would have been unable to approve the paper forms for marine service operations without permission from the shipping company (see red line in Figure 5). These problems can occur when the oil platform sends a digital request to the vessel (see red line between office systems and the oil platform in Figure 5). This type of request does not appear in the marine operational systems. As a result, the captain has less opportunity to check it during collaborative DP and marine service operations. This event also prevents the first officer from monitoring the containers (see red line in Figure 5). Therefore, according to our disciplinary perspective, there is a broken line between the cooperative work of the DP and marine service operations. This broken line indicates the limitations of engineering practices in their ability to adequately support human safety during the design of marine operational systems. While one may call this holistic human safety issue a typical event, this paper refers to the phenomenon as an imbalance line (see Figure 5).

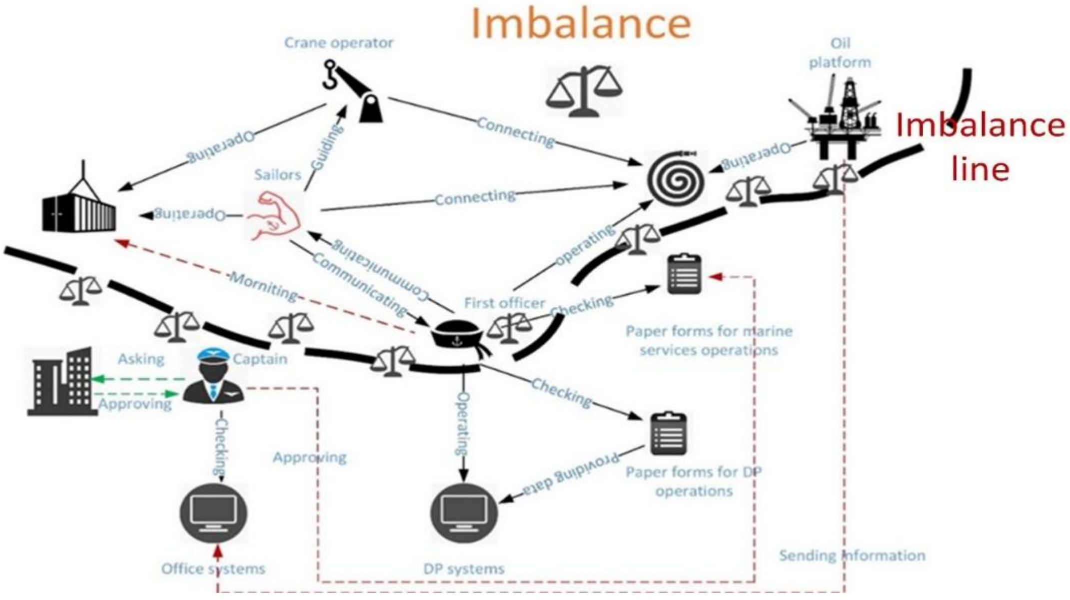

Figure 5: Imbalance occurs when a change request is received and the captain leaves to check and approve it. Red dotted lines indicate missing features in marine operational systems during human and non-human interactions.

Human safety is a dynamic performance process that occurs between marine operators and marine operational systems. We found that safety issues rarely transpire during individual work practices because marine engineers, engineering designers, and human factors engineers are capable of planning marine operations with minimum human safety issues by debugging technical errors, applying good interaction styles, and preparing informative maritime course training once a marine operational system has been built. However, safety issues arise within cooperative marine operations when unusual issues, such as the changes to mud type in the above example, emerge. These issues can impact anything from the work procedures of marine operators to the technical aspects of marine operational systems.

Hence, although the first officer hands over his work to the captain, he also plays the role of shift supervisor, coordinating information and communication to the captain (e.g., observing the crane and communicating with the sailors on deck). If we use the concept of boundary object to analyze these safety issues, we can determine that human safety is a boundary object that is well understood within each engineering community and that every community holds different opinions and engineering standards in their approaches to safety. Regardless, it is doubtful that engineers can solve human safety problems within a cooperative work environment. We see that human safety problems in marine operational systems can be solved individually within each engineering community and that human safety is flexible enough for different engineering practices to effectively develop marine technology for individual marine tasks, such as DP operations. However, human safety is not supported when different marine operational systems come together for cooperative use, as these collaborations lack communication and interaction between sub-tasks and are incapable of producing revisions to the work procedures or engineering design processes of marine operational systems.

7. From vignette analysis to suggestions for the safe design of marine operational systems

7.1 Visualizing in-situ work practices

When a captain hands his work over to the first officer, the office systems should synchronize the DP systems with real-time weather data. This is important for the first officer so that he may keep the DP operations as safe as possible, which in turn can impact the success of the marine service operations. The sailors on deck who guide crane operations should have an open communication channel with the crane operator. In addition, this channel should be available to the first officer and the crane operator so that they may safely pump mud. It would also help the first officer to learn how to shift mud inside the vessel so that he can maintain balance during marine service operations. Furthermore, paper-based forms should be updated to ensure that new and correct information is provided to both the captain and the first officer. In the case that this paper explored, this would have allowed the captain to have checked and approved the change request without increasing the workload of the first officer.

Marine service systems should provide information about a vessel’s balance status, or at least reveal to the first officer the amount of mud that needs to shifted from a certain container to another in order to balance the vessel. If human safety is related to the internal relationship between marine operators and marine operational systems at the individual level, then holistic human safety is related to the external relationship between various marine tasks at the cooperative work level. As an example, when the DP system expands to become integrated with marine service operations, the first officer becomes involved with the internal human safety of DP operations. In addition, he is simultaneously involved in marine service operations with the captain and other crew members, such as the sailors on deck. This expanded role can result in minor safety issues as the first officer may become overwhelmed by these additional duties. A technical error in the marine service systems may not be a DP operations’ issue. However, as this internal error can interfere with cooperative work performance, it will also not be an isolated error.

This paper’s primary author examined the internal relationship between marine operators and marine operational systems and the external relationship between various marine tasks at the cooperative level with the marine operators by asking them, “How do you understand the role of human safety in cooperative marine operations?” They answered as follows:

> First officer: If I could have real-time information regarding my operations, both DP operations and marine service operations, I could manage both operations safely. I also need a clear communication channel between the crane operator and myself, between the sailors on deck and myself. In that case, I could confirm the information that I need to do my work. I think that is very important. Thus, safety, for me means I can successfully operate those computer systems internally and deal with my colleagues. Then I can exchange information and communicate with others for cooperation.
>
> Sailors on deck: We think communication is very important. We need to know who we are talking to and what information we need to pass on. We also need to know the work plan in order to position the containers in the right places if this is changed. We may not need to know how the crane operator works, but we want to make our own work better and show safety to others.
>
> Captain: I think it is important to have good interactions with information between different working groups. If I can approve the change request immediately here rather than trotting back and forth, and if I can also control the DP systems with correct information, then I think it is will be safer and more effective for the safety of everyone. I also think not all information needs to come to me to process and control because I am also on my own operation and I have to focus on my work. With good technical systems, skilled crews, and great communication systems for exchanging information, I believe we would have good safety.

Safety in cooperative marine operations is understood by marine operators as the material they use that surrounds them as they cooperate with others. In their opinion, they need to use the correct resources rather than be issued orders to properly complete tasks. In their understanding, human safety is a process that occurs in both the technical and human domains. To a create a safe and cooperative environment for their operations and each other, they focus on technical problems and adapt to their own and the technical system's performances. As the first officer noted:

> Our team, for example, the captain and I [the first officer], may not be familiar with others in most operations in a year. Hence, human safety in my understanding is how your work can cooperate with others and their environments safely.

While this statement is speaking on behalf of marine operators, it also confirms that the tools and systems they use play a part in cooperative work. Marine operators are experts in their field. As a result, marine operational systems should provide solo operations for cooperative work operations but also allow for autonomous relationships to form between different operations' cooperators. This understanding creates a space where human safety is robust enough to enable different engineering communities to work on an operation according to their own standards and internal relationships (see inside the circles, red lines, and mutual ways (shared practices between different engineering communities) in Figure 6). (Lampland and Star, 2009). It should also be flexible enough to produce a holistic understanding of the external relationships (Burman, 2004) that exist within cooperative marine operations (see the broken black line in Figure 6).

As an example, sailors need to communicate both verbally with crane operators and with gestures (see red line in Figure 5). Crane operators also need to communicate with the oil platform in order to assist the first officer, who can then obtain information regarding the services he is working on (see red line in Figure 5). In addition, the captain should be able to approve marine service operation forms digitally and without the need to relocate to a separate location. The shipping company should also be able to access the office systems on the ship's bridge and approve requests sent by the captain. In other words, office systems should not be isolated from marine operational systems. Rather, office systems should be improved to assist both the captain and the first officer in their working positions of the marine operational area. In sum, human safety should be transferred from a high level of cooperative operations to marine service operations, DP operations, and office operations as three individual digital environments (see three circles in Figure 6) with their own marine operators and operational systems.

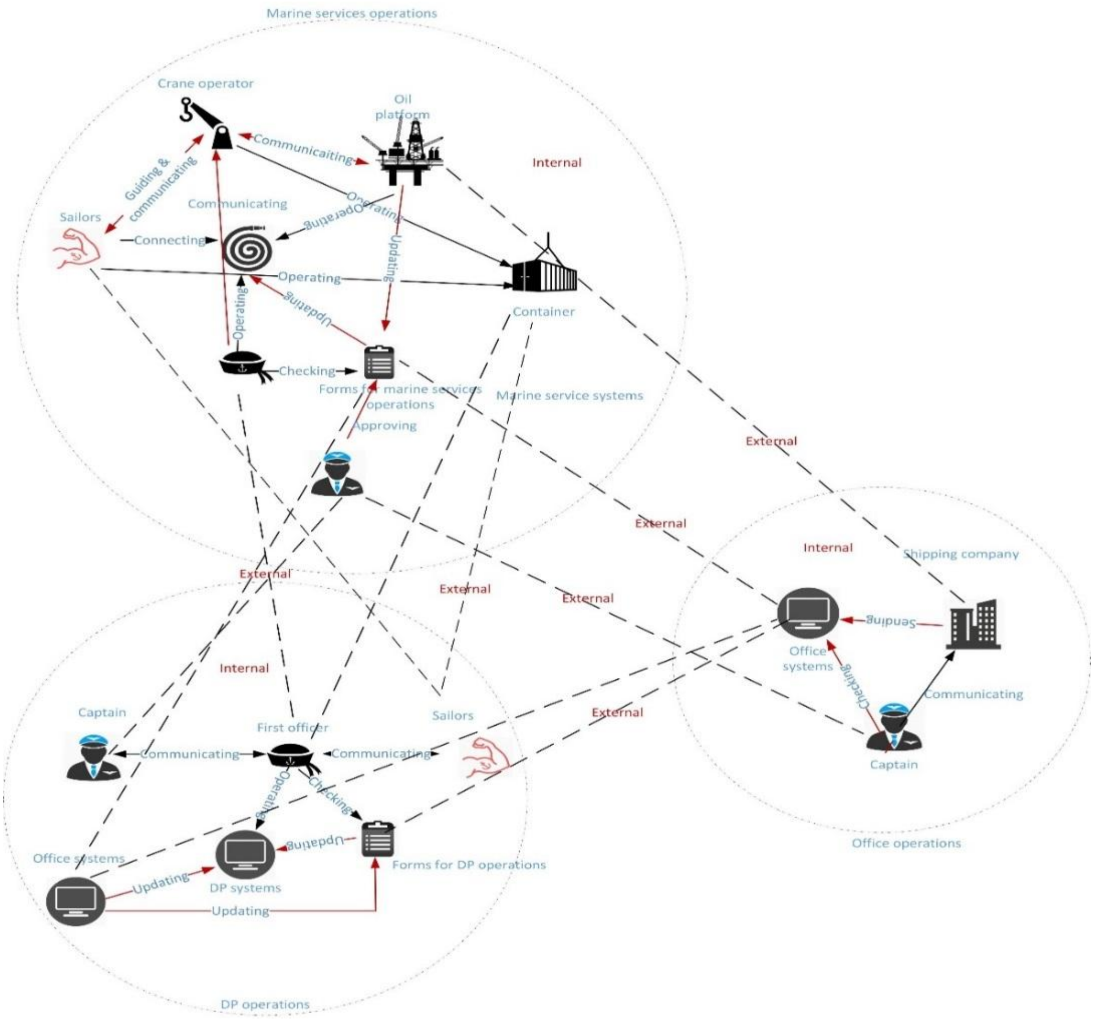

Figure 6: Marine operational systems for internal and external relationships

8. Integrating engineering communities' practices in the support of marine operations safety design

Through our analysis, marine operations safety may no longer require engineering designers and human factors engineers to prepare marine operational systems, nor for marine engineers to train marine operators in work procedures that adhere to the rules for different marine tasks that are covered by marine operational systems. In situ work enables the use of field work as an engineering practice. Its usage can remind maritime engineers that pre-planned work procedures may not be suitable for professional marine operators. Work procedures should be revised to match the in situ cooperative work of marine operators who are involved in marine operational systems. Design researchers should engage in cooperative work environments and observe and interview marine operators to better understand what constitutes cooperative work and how cooperative safety can be formed for every marine task. By reshaping operation systems to support safe and cooperative work, this activity can aid in the design of marine operational systems so that they better support holistic human safety. This type of research could also help in the identification of improvements that can be made to the individual engineering community's practices and technical equipment, decreasing the rate of technical errors, interaction failures, and communication faults. Finally, these steps could allow researchers to better support individual work practices within operational systems.

It is worth noting that the design of marine operations safety is an iterative process. For instance, field studies can aid in the development of knowledge about marine operators' in-situ work practices prior to the establishment of a unique cooperative work environment. The in-situ work practices of operators can reveal problems that exist within current cooperative work environments. They can also lead to better design in the positioning of new functions, new operators, and new work procedures.

The design of cooperative work environments requires engineering communities to transfer more than their design and engineering activities. Design research and engineering studies must work together to form a more holistic understanding of human safety and work practices. Practices in the engineering communities could benefit from a richer discussion about the stabilization of socio-technical systems by encouraging design researchers, engineering designers, human factors engineers, and marine engineers to collaborate in the production of socio-technical innovations that can improve cooperative work.

Supporting human safety in the practices of engineering communities requires the creation of a boundary object (Ellinas et al., 2016). Researchers have supported the value of enabling engineering communities to share their practices with other communities (Petersen and Buch, 2016). This can be achieved by applying knowledge (Buch, 2016) that exists outside of the current ecology of engineering work. The primary author of this paper is an advocate of Schmidt's (2011) paper, which asserted that collaborative engineering communities should enable socio-technical innovations from the bottom-up so that they involve professionals in the field and make their performances visible during the developmental processes of socio-technical systems. In addition, collaborative engineering communities could successfully cooperate with other research fields in an effort to bring about new ideas and encourage other organizations to share information across boundaries that exist between the engineering communities. Engineering work requires a considerable amount of reporting from the field, in addition to the formation of relationships that are based on negotiations for maneuverability between different engineering communities. Field work can shed light on the development of technical systems that support cooperative work practices, which can improve human safety.

If human safety is considered to be a part of the greater picture of engineering community practices that incorporate both individual and cooperative work, traditional engineering in the maritime domain may change during the design of systems that support cooperative work. Design researchers observe in-situ work practices to make cooperative work visible. These work practices are solidly embodied by the performances of marine operators and can offer non-technical knowledge to marine engineers who typically do not address them in their work. As Vinck (2014) asserted, "field work can emphasize the importance of the dynamics of interaction and exchange between actors, the production and circulation of multiple intermediary objects, and the building of the compromises between actor professionals with varying viewpoints." In summary, actors become connected through the definition of problems, the integration of knowledge, and the search for solutions and their implementation. The practices of engineering communities include reports about daily work tasks. These reports refer to the ways in which people make use of their work skills and share their perspectives by pointing out details. Engineering community practices thus involve the collective knowledge of multiple actors so that they may benefit from both tacit- and formal-types of knowledge.

In sum, when design researchers engage in field work, they are able to map out problems related to technical issues and work procedures through observations and interviews. On the one hand, these efforts can inform marine engineers to modify their work procedures so that they align with the in-situ cooperative work practices of marine operators who are attempting to address safety concerns. These endeavors can also compel marine engineers to take part in the development of marine operations safety rather than isolating them from the process as these work procedures are created. As mentioned, work procedures are dynamically related to the in-situ work practices of marine operators. It is therefore important that marine engineers be involved in marine operations safety design so that the in-situ work practices of marine operators and the work procedures of marine engineers each contribute to the design of marine operational systems for engineering designers and human factors engineers. On the other hand, these efforts can influence engineering designers and human factors engineers to make changes to marine operational systems that better support cooperative safety practices, and which are based on field work and new working procedures rather than the development of operational systems that only support the work of individual operators, amongst marine operators.

Marine operational systems support marine operations safety. It is therefore vital that marine operational systems are designed to consider the in-situ work practices of marine operators. By observing the in-situ work practices of marine operators and collecting knowledge from marine engineers and design researchers, marine operational systems can adopt a holistic approach to human safety for the engineering practices of design and human factors engineers. Cooperation between these different actors (design researchers, marine engineers, engineering designers, human factors engineers, and marine operators) involves the occurrence of multiple activities at specific times and places. According to Suchman (2000), these times and places are interwoven with the network or relationship that actors strive to connect. As boundary objects are created from within field study, the process of conducting field studies reveals that human safety is comprised of the actors who are involved, the systems and equipment that are used, and the way that cooperative work is carried out.

9. Conclusions

In order to adopt a holistic view of human safety in the design of marine operations, this paper employed boundary object to analyze the concept. By evaluating a series of vignettes, the paper determined that human safety can be identified and supported within each engineering community's practices. However, human safety does not address the in-situ work practices of cooperative marine operators who perform marine operations. Indeed, there is a gap that exists between marine operators, marine engineers, engineering designers, and human factors engineers during the design of marine operational systems that are built to support holistic human safety within cooperative marine operations. Thus, we promoted the collaboration between design researchers who engage in field work and marine operators who promote human safety. We then used this partnership as a boundary object, wherein marine engineers, design researchers, marine operators, engineering designers, and human factors engineers could cooperate in the design of holistic marine operations safety. In this manner, human safety can be designed by using the work procedures and in-situ work practices of marine operators to inform the design of marine operational systems that support safety within cooperative operations.

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