Are Current Usabilty Methods Viable for Maritime Operation Systems?

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Abstract—**Usability is strongly linked to loss of life in many technical and incident reports. Maritime operation systems are sociomaterial systems in which many operators work cooperatively on ship bridges and decks. However, current usability methods focus more on individual interaction. Hence, applying such methods to maritime operation systems leads to several problems. Moreover, a few evaluation methods are hard to duplicate from other research fields owing to various reasons. In this paper, we indicate that maritime operation systems should consider cooperative work for providing a complete picture of interaction issues. In addition, evaluation for maritime operation systems needs deeper understanding of the relationships between human beings and systems. We discuss several usability methods that have been extracted from other close field (e.g., aviation systems, fishing systems, maritime navigation systems, and nuclear power plants) and apply insights from such fields to our case – deep-water anchor handling operation. We assert that usability in maritime domain should be expended as interaction in ecosystems such as the maritime operation system. We suggest that interaction study in maritime operation systems can offer a path to draw and measure a complete picture of maritime operation rather than purely focusing on individual usability issues.**

Keywords-Interactions; usability; maritime operations; sociomaterial systems.

I. INTRODUCTION

In recent decades, technological advancement has reshaped the patterns of maritime offshore vessel operations. Engineers design many types of offshore vessels for multiple operational requirements and environments. Ship bridge systems are divided into two different categories—maritime operation systems (after ship bridge) (Figure 1. Maritime operation systems) and maritime navigation systems (Figure 2. Maritime navigation systems). The efficiency and effectiveness of maritime operations hugely influence mariner safety issues [1]. An increasing number of accident reports [2] identify dangerous system design characteristics and interactions among various embedded maritime operation systems as the main reasons for maritime accidents [3]. The usefulness of maritime operation systems is strongly linked to loss of life, significant property damage, or negative effects on the environment [4].

Maritime operation systems are complex systems. Individual operators cannot accomplish maritime operations alone, and cooperation among multiple operators and subsystems are required. The associated operation environments involve greater levels of complexity than a regular office. Maritime work is more or less similar to a society, and it involves not only technical work, but also social communication from task to task [5]. Operators, systems, operational behavior and social communication build a sociomaterial system in maritime operations. IT designers consider such complex sociomaterial systems as an infrastructural setup [6] in which economy, technology, and system stakeholders are involved [7]. However, according to Pomeroy and Jones [8], maritime systems are a combination of human operators, technical elements, and physical equipment. In addition, they point out the necessity of considering sociomaterial systems in the broadest sense when dealing with marine safety. The study presented in this article is limited to usability issues within the scope of maritime operations, and we consider an abridged complex sociomaterial system comprising human beings (operators on the ship bridge and deck operators who work on maritime operation tasks) and maritime operation systems (Figure 3. Ship bridge).


Figure 1(left). Maritime operation systems (Copyright: Kongsberg maritime, Norway); Figure 2. Maritime navigation systems (Copyright: Ocean Industry Concept Lab & Maritime Human Factors Lab, Norway).

Traditionally, usability is not concerned with safety, but with understanding interaction mechanisms and using this understanding to improve design [9]. Usability refers to efficiency, effectiveness, and satisfaction [10], and it is widely used to evaluate web pages[11], mobile information systems [12], and general physical ergonomic issues [13]. Maritime operation systems involve many interrelationships among of multiple subsystems for different maritime operation tasks and challenging work environments. Consequently, they are much more complex than other sociomaterial systems. For example, dynamic positioning systems, drilling systems, alarm systems for operations, and dragging oil and deep water systems are integrated for maritime operations. Operators face many displays/subsystems (Figure 1. Maritime operation systems), and they need to communicate with other operators within and outside the ship bridge (Figure 3. ship bridge). Such distributed collaboration and complex sociomaterial interaction poses interesting questions for researchers—whether current usability methods still make sense for increasingly complex sociomaterial maritime operations, and what are strengths and weakness of current usability methods?

The usability of complex sociomaterial systems is rarely studied in the context of maritime operations. There are a few studies pertaining to usability in the maritime domain, for example, a study on fishing vessels [14] and one on maritime navigation [5]. Nevertheless, these studies focus on physical equipment as opposed to systems. In addition, consideration of usability issues in the design of most large and complex systems in the maritime domain is largely absent, for example, Henique et al. [15] largely neglected cooperative IT work in their research.

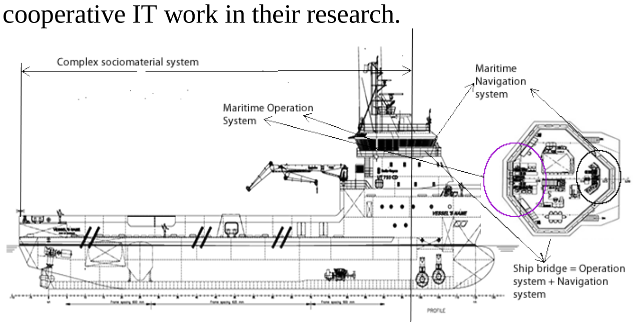

Figure 3. Ship bridge: Complex, sociomaterial maritime system (Copyright: unpublished resource, Maritime Human Factors Lab, no copyright restrictions)

This situation is understandable because we assume the current usability approach to be developed when the personal computer came into use, and it is applied to the Internet and various consumer electronics. Usually, there is no need for user cooperation when interacting with these products, and safety is not the first quality objective. However, maritime operation systems comprise many integrated subsystems with highly complex interrelationships, and, therefore, current usability methods are difficult to employ in such scenarios. However, maritime operation systems share strong similarities with other research domains such as aviation systems, maritime navigation, fishing systems, maritime rescue and coordination centers, and nuclear power plants [16]. Hence, it would be fruitful to borrow knowledge from other research domains to understand usability in highly cooperative work and complex systems.

Hornbæk [17] suggests that usability measures should be formulated on the macro, as well as the micro levels. In this manner, researchers can capture a global usability picture of complex systems. Thus, in the following text, we draw on the presentations described above to examine current research on usability in different disciplines. This consideration is necessarily both practical and theoretical because we aim at examining how current usability methods can be used practically at a micro level (individual and group usability testing) and the extent of theoretical understanding of usability for maritime operation systems at the macro level (a global usability understanding of entire maritime operation systems). While, it is still difficult for researchers to understand the relationships between humans and complex, sociomaterial maritime systems and their combinations from the two levels. Maritime operation system as an entire system for cooperatively operating by operators, it is important to obtain a picture of usability relations between each sub maritime task, which executed by each individual operator. Hence, interaction mechanism is a clear choice that can offer an opportunity to understand such relations, contrasts, problems, and opportunities in the maritime IT domain, e.g., the relations of several usability problems in one maritime task.

Section II we present the method we use in this state-of-art. Section III presents some cases within and outside the maritime domain. We apply current usability methods to our case of deep-water anchor handling in section IV. In section V we conclude that usability in maritime domain should be considered as interaction in complex environment.

II. METHOD

Getting a clearer idea of how to apply current usability methods to maritime operation systems is indispensable. Additionally, deliberating usability of entire maritime operation systems in a theoretical way is urgent because it would help ascertain unnecessary usability methods before the empirical studies.

Hence, we apply four research criteria to the research domain of usability evaluation in complex sociomaterial systems. Usability, ship bridge systems, maritime system, and sociomaterial system are the search keywords. We have searched databases such as ACM and IEEE Xplore Digital Library, Journal of Usability Studies, Marine Science and Technology Journal, Springer link, and Computer–Human Interaction Journal and Proceedings. Our goal is to map out the current usability methods used in maritime operation systems. Thus, by understanding usability methods from both other research fields and the maritime domain, we seek to find a way of promoting usability methods in the maritime industry. The paper includes a review of usability evaluation from the earliest to the most recent research on complex sociomaterial systems in control rooms, including aviation system, maritime navigation systems, fishing systems, maritime alarm systems, maritime rescue and coordination centers, and nuclear power plants. All work in these domains is highly cooperative among the operators, and several complex support systems are involved. In addition, in all these domains, the potential threats to human life and the environment in cases of abnormal system behavior are great.

III. CASES WITHIN AND OUTSIDE OF MARITIME DOMAIN

We chose the following cases because they cover most usability methods in terms of micro usability analysis. Moreover, the newest usability method—systems usability—attempts to understand systems at the macro level.

As complex sociomaterial systems, aviation systems attract considerable attention in this field. Mahemoff et al.

[19] evaluated an aviation system and described a pattern-based usability approach that was adapted from Mahemoff and Johnston's research [19]. They proposed that usability patterns should be robust; task–efficient; and effective in terms of user–computer communication, comprehensibility, and flexibility. This study concluded that heuristic evaluation, 'think aloud', and cognitive walkthrough are appropriate methods for a complex sociomaterial system and applied these methods to design an example alarm control system for flights. On similar lines, studies have been conducted for usability evaluation of systems such as the UK's air defense control [20], industrial process control [21][22], healthcare [23], aviation and space [24], transportation [25], and nuclear power plants [26].

In the maritime domain, usability is not the first priority of research. Most studies in this domain focus on human-centered design, with limited or no evaluation of system segments. In terms of usability in ship bridge systems, the most notable suggestions have been to design a useful ship bridge, navigation system, maritime mobile application, and so on. For example, researchers have used eye-tracking data to analyze usability issues on bridge systems [27]. Lützhöft et al. [28] conducted a series of navigation systems studies based on observation, interviews, questionnaires, and video recordings. They proposed that in a navigation system, large, shared interactive work surfaces could ensure good support for cooperative work planning and execution. In a parallel study, they present an application based on this type of a shared system to explore the potential of tabletops for maritime navigation.

In a study of maritime rescue and coordination centers, Mills [1] claimed that approximately 300 distress calls from both text entries and voice systems are sent in error every year; that is, the vessels sending these calls are not distressed but they did send emergency messages or distress alerts (e.g., 'Mayday'). Through heuristic evaluation and think aloud analysis, Mills found that the operators did not understand marine operation systems and made wrong system operation decisions. The most obvious fault was false alarms in the ships' systems [1]. In a follow-up study, Mills [14] discussed the usability problems of acoustic fishing aids on small fishing vessels, with a focus on data interpretation and comprehension. Through sequential heuristic analysis, the study pointed out that many operation errors occur because of the poor usability of interfaces. Also, the study found that errors occur because operators do not correctly understand the presented information [14]. Wilkinson [29] stated that improving the usability of user interfaces could help operators understand presented information and convert it into a correct decision or control action within a maritime setting. However, both Mills and Wilkinson did not elaborate on methods of improving the usability of these operation systems.

To understand the interaction mechanisms, human activity, and how users live with technology, Savioja et al. [30] conducted a study of nuclear power plants. They developed a method called 'systems usability'. This method builds on the activity theory [31]. Through this approach, researchers can understand and analyze different levels of operations and actions of individual users [30]. In practice, this method uses a predefined task. The evaluators observe the completion of this task to find certain measures such as errors and completion time. In addition, situation awareness is used to evaluate the user's performance. In a follow-up study, these researchers explained that they used the activity theory in complex systems evaluations for the following reasons [31]:

> …. Activity is understood as historically and culturally developed. Hence, the central aim in the analysis is to find out the current state of affairs but also their historical roots and possible trends from which development is proceeding. The approach suits well the needs of control room evaluation in a state in which hybrid technologies have been implemented and more profound modernizations are under design. In order to understand whether the development of tools is proceeding in a good direction, the wider historical context tools must be understood. (p. 259)

Two units of activity [32] are used for analyzing the work in nuclear power plants —object-oriented and mediated. By means of object-oriented activities, the systems-usability method analyses work execution sequences, way of acting, and experience in action. By means of mediated activities, this approach analyses the relationship between a subject and an object when mediated by tools (e.g. in the NPP studies, the user interfaces are the tools). The author's logic behind this approach lies in the elaboration of on mediation by distinguishing between two different functions of tools in an activity—instrumental and psychological. Another type of activity used is communicative [31]. Through these three functions (instrumental, psychological, and communicative) and object-oriented activities, the systems usability approach tries to cover a system's overall meaningful role in an activity, such as the manner in which humans conduct themselves in human–technology interactions and the global, society-defined purposes and objectives of a user's different task levels.

IV. APPLYING CURRENT USABILITY METHODS TO MARITIME OPERATION SYSTEMS

To examine how current usability methods could help researchers in the maritime domain, we apply these methods from abovementioned various research domains to our example of deep-water anchor handling operations (DWAHO). In DWAHO, two groups of operators on two vessels operate two maritime operation systems during anchor-handling tasks. An additional anchor-handling vessel (AHV)—the secondary AHV—is used to relieve some of the chain weight held by the main AHV (Orange unit, Figure 4. Deep-water anchor handling operations). In this operation, two systems (on two vessels) perform one shared task (positioning an oil platform, shown in orange in Figure 4). The main AHV does more than simply holding the chain. Before holding the chain, the main AHV must follow several procedures, including, among others, drawing anchoring arrangements, offshore installation draught during anchor handling, and measuring water depth [33].

The operators of the main AHV perform different roles during operation. For example, two or more operators conduct the different procedures. All operations use different subsystems simultaneously (Figure 4. Deep-water anchor handling operations), such as dynamic positioning systems, drilling systems, alarm systems for operations, and dragging oil and deep-water systems.

A. *Micro level of usability evaluation*

In an AHV, the interactions are not static. The combination of operators, operation systems, and ship deck operators change from task to task. Barrett [34] proposed that boundary relations such as boundary cooperation and strain, too, change from task to task. To test the usability of AHV systems, for each maritime task, we should consider a group of operators rather than an individual operator. Otherwise, the test would be too narrow and limited to determine the global usability of entire maritime operation systems.

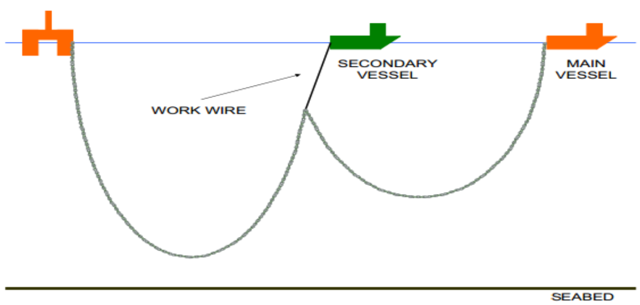

Figure 4. Main AHV is assisted by secondary AHV during DWAHO[33]

However, in aviation system studies, Mahemoff et al [19] did not discuss the mechanism of interaction or the evidence gathered for the method that can best contribute to knowledge about general issues of collaborative work and the potential role of technology and users. Similarly, Lützhöft et al [28] discussed design for marine collaborative settings in their maritime cooperative application study but with minimal stress on efficiency, effectiveness, and accuracy. Even though Lützhöft et al [28] focused on the interaction mechanisms, the usability approach was more or less neglected. The NPP-based studies [30][31] do not clarify the definition of a boundary when an entire environment allows for dynamic changes in groups, systems, subsystems, and combinations of these.

Anchor handling operation systems are special because they come from shipyards, thus requiring manufacturers to deliver assembled solutions, and these solutions are usually needed at different levels of integration, ranging from the physical proximity of equipment to full-scale data-level integration [35]. Furthermore, current system products are a an alternative manifestation [36] of component software elements. An evaluation of a different context of technology-in-use [37] in the maritime domain requires an approach different from merely replicating methods meant for other research domains, where most systems are not developed by decomposition.

B. *Current usability methods in system fragments*

Current usability methods mostly are conducted at the individual level. Nevertheless, there exist differences at micro levels of usability evaluation between other complex sociomaterial systems and anchor handling operation systems in terms of their natural work environment context. Anchor handling operation environments are usually extremely unstable. Wind and stormy waves invariably affect usability experts evaluating maritime operation systems, which increases the difficulty involved in evaluating these systems. Therefore, usability experts are required to account for natural environmental factors that may affect their evaluation outcomes. In addition, the data collection methods used in another domain's study cannot be duplicated directly because of the following reasons:

- The observation of maritime operations is different from the observation of other research domains. Most anchor handling operators may have undertaken only several intensive training courses before they move onboard for hands-on learning [38]. Generally, experienced operators assist the new operators in performing their duties. In contrast, operators from other research domains are trained for several months before they operate systems independently [39]. Thus, observation processes vary, and errors are easier to spot in maritime operations especially when operators need training/supervision for completing a task. However, as outside observers, usability experts should play a role as participant observers to develop a descriptive understanding of the way of life of the study group [40]. Whether the interface, computer screen, procedures, and analogue indicators are simply very usable or seemingly smooth in operation should be judged not by the standards of usability experts but by the participants.
- Most other studies are conducted in a simulator environment, and their usability evaluation is based on a new simulator in addition to the data obtained by methods of questionnaire and interview. In this context, it may be difficult for experienced operators to express realistic problems. However, the interfaces of anchor handling operation systems are computer-supported tools used in a real environment. Thus, it could be easier for an experienced operator to provide detailed descriptions of a real working place, as well as conversations between researchers and their participants [41]. Therefore, from the productivity viewpoint, it would be better if researchers developed an evaluation method for maritime IT designers, who decide on future uses for maritime new products. Again, environments of other research domains are steady compared with a ship bridge. Normally, maritime operation systems are operated in unstable working conditions at sea. In addition, bridge operators have to communicate with other operators on deck or other vessels and oil platforms from time to time. Therefore, a greater number of recorders and usability evaluators would be required compared with those needed in the systems-usability method.

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- Eye tracking can help researchers identify obvious usability problems, but eye-tracking data can only tell the interests of users as opposed to explaining why users pay attention to some information and ignore other items. Usability experts cannot go deeper into the user's mind. It is difficult for these experts to capture personal meaning [31], so it would be difficult for researchers to evaluate user perceptions.
- In addition, think aloud, cognitive walkthrough, and heuristic evaluations are difficult to conduct in a situation in which the dynamics of the process largely determine the pace of the situation [31][16]. Nonetheless, knowledge and expertise are embodied inherently in complex sociotechnical systems [6]. Think aloud has proved useful for identifying usability issue–related collaborative problems in mobile collaborative systems within the maritime domain [42]. We believe it depends on the manner in which researchers conduct interviews and ask questions [41] in their conversations with maritime operators.

C. *Macro level of usability evaluation*

From the interaction viewpoint, in nuclear power plants studies, the understanding of 'object of activity' continues to be focused on individual work. This can be understood as a micro level of usability evaluation [30][31]. In the action–objective relationship, the focus is on the interactions between individual users and computer systems. The macro level of usability is evaluated using instrumental, psychological, and communicative analysis methods to investigate the manner in which a user interacts with user interfaces and environments in groupware. These ideas are explained using the term 'communicative' [31].

However, it is impossible to understand usability over an entire environment because a few aspects emerge in unfolding activities that cannot be understood in the absolute sense but only as 'relative activities' [43]. Evaluation of technologies-in-use cannot be carried out in a black box. Maritime operation is usually not only a collection of each individual operator's work and its reflections on group work but also cooperative work among individual operators through interactions. For example, multiple operators manipulate different systems on the ship bridge in anchor-handling operations. Moreover, these operators communicate with different operators on the ship deck during the same or different tasks at the same or different time. Different operators within and outside the ship bridge can be seen as different groups. Furthermore, maritime operation reflects different relations across each boundary between groups, including systems, operators, and social contexts evolving within these operational processes.

Hence, when considering systems usability in the maritime domain, we overlook group interactions and cross relations among different working groups. Schultze and Orlikowski [44] studied the performance perspective in globally distributed, immersive work and argued that in a set of activities and interactions engaged in by various actors, the actors' relationships and mobilisations produce certain effects, such as actions and interactions that are no longer independent but deeply connected and grounded. We concur with this understanding and want to apply it to the maritime domain. We cannot see each maritime operation task as already defined and fixed because there are some invisible operators present in each maritime operation, and cooperation across operator groups is dynamic. For example, in an anchor-handling operation, deck operators assist an operator on the ship bridge; however, in another task, these deck operators may play another role in different operational processes with another operator on the ship bridge. We should treat the group interactions on the ship bridge in terms of the performativity [18] of the systems engaged in the operators' practices. The performativity of maritime operation systems is sociomaterial [18][45], as established by different maritime tasks in which systems are designed and engaged in social practice of operators.

As sociomaterial practices, maritime operation on the ship bridge is a significant source of information about why, when, where, and how maritime operators interact with the anchor handling system and communicate with which operator on the ship deck. This information is much complex than an experimental result that normally takes place in a laboratory. Researchers have no capability to grab the relationships between systems, operators and their combinations. Moreover, only a piece of system can be studied in a laboratory. There is a huge gap between reality and virtual environment. Keeping these questions in mind, operators within and outside ship bridges cooperating in each specific maritime operation task could help understand those invisible activities. The usability measurement idea then moves and reconfigures the dynamic and transformed relationships among interaction issues within and across groups. Such an idea also extends and intensifies usability measurements within maritime operations as an interaction, which would be very helpful for designers, who could then clarify dynamic boundaries for groups, systems, and the associated social context.

D. *From usability problems to interaction in ecosystems of maritime operations*

After applying usability methods to a maritime case, we realize that current usability methods are insufficient for evaluating maritime operation systems. We assert that the term of usability makes less sense in maritime operation systems. The reason is that usability focuses more on individuals. Logic relations of each individual usability problem in a complex environment of maritime operations are overlooked. The relations between individual operators, system segments, and their combined interactions could not be fully understood in maritime operation systems. Hence, usability methods have little power to illustrate such relationship. In this case, researchers inadvertently lose focus on the entire maritime operating systems but pay more concentration on individuals, systems segments without deeply touching the interaction between operators and systems in maritime operations. On this occasion, usability

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problems should be considered as interaction issues in an ecosystem [43] whereby operators live in their working contexts to reveal interaction issues. In this manner, a usability issue is not standalone but instead integrated into an interaction. From an interaction viewpoint, we can gain a complete picture of the maritime operation system.

V. CONCLUDING REMARKS

Although we mapped the drawbacks of the abovementioned methods in evaluating complex systems, it does not mean that current usability evaluations are not useful; in fact, they may provide some useful data for understanding interaction in empirical investigation, such as observation and interview. To avoid the limitations of individual methods, Neale et al [46] recommend that a multi-method evaluation approach, including observation among other methods, be used in an environment in which multiple users use systems in a work setting. Ship bridge systems are typical complex sociomaterial systems, so it is necessary to develop new usability measures for this special context-in-use. The measures should not be restricted only to the micro level, covering only usability for individuals or group operators for one specific task, as is the case with most studies thus far. Instead, they should determine how specific technologies-in-use enact different sociomaterial environments. This is important in every maritime operation to ensure holistic evaluation of maritime operation systems.

Based on the understanding of dynamic relationships in and across group interactions, in the future, what we call a “usability issues” could be a construed as an ‘interaction’ through the identification of boundary relations among different working groups and working environments. This should be treated as fundamental ‘interaction network [47]’ from the maritime operation systems viewpoint, where human beings and their working environments are investigated holistically. To achieve these assumptions, empirical studies on ship bridges that further investigate the relationship between interaction issues are needed. Hence, we will collect research data aboard in the future and to investigate the interactions as our second step of this project.

To conclude, we suggest the following tips to help practitioners who plan to undertake interaction mechanism for maritime operation systems:

- When studying complex systems, concluding usability results for an entire system should not only test segments of the system. Mapping out usability relations of systems’ segments is important. Hence, the focus should be shifted to interaction in ecosystems.
- Understanding maritime work of interaction in a complex system is important and useful for outlining interaction relationships in a big system picture. The work in maritime operation systems may involve multiple tasks and operators. The relationship of operators, tasks, different operator groups, and their combination should be understood as a whole.
- Humans and technology should be considered together. The relationship between human operators and technology is strongly connected. Understanding the ecology of this relationship will render a better understanding of interaction relations in interactions of series work as well as a complete system picture. Although we use sociomaterial practice [18] to interpret the relationships between humans and technology, other theories also can serve such analysis, e.g., actor-network theory (ANT) [48]. For example, ANT may better explain the network of operations in complex systems.

The future work of this project is to collect data on ship bridge rather than perform experiments in a laboratory. Our purpose is through interpreting the interaction in maritime operation systems to measure the current design of maritime systems in industries. In turn, we aim to use data analysis results to develop a way for the future evaluation of designing maritime systems.

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