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Human Interactions Framework for Remote Ship Operations

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Abstract— **The concept of unmanned ships capable of being controlled remotely is now beyond the idea and will start a revolution in maritime industry. In this context, remote ship operations refer to processes of controlling the vessels from distance such that operators obtain information from sensors. Thus, assessment and improvement of human interactions can enhance the overall performance of remote ship operations. However, there are unknown *(i)* human-human and *(ii)* human-machine relationships in remote ship operations, which increase the complexity of ship operations and therefore affect the overall system performance. This paper introduces a human interaction framework in remote ship operations domain in order to maximize system performance by minimizing conflicting operations. Hence, the proposed framework identifies the human interactions in remote control centers as well as the main differences between remote and non-remote ship operations. The current paper employed human system integration (HSI) approach in order to consider human as a sub-system. In this respect, literature review and human factor engineering technique (HFE) named similar system analysis were utilized to collect data and accordingly coding process was performed to analyze collected data. The proposed framework updated the earlier models of human-automated interactions and tailored to fit in the context of remote control centers. Besides, differences between remote and non-remote operations provide insight into human interactions in remote ship operations and consequently facilitates performance improvement actions. As a result, the proposed framework provides a solid understanding of human as a critical sub-system in remote ship domain so that gained knowledge could be used by designers and engineers.**

I. Introduction

Remote and autonomous ships will change maritime industry to great extent, in which it will affect maritime players such as shipping companies, maritime operations, ship builders as well as new technology companies. In 2016, industrial and government actors in Norway have established the Norwegian Forum for Autonomous Ships (NFAS) in order to promote the unmanned ship concept. It is even more pronounced that unmanned ships in form of remote-controlled ships will be in commercial use in the near future in order to reduce operational and maintenance cost as well as increase loading capacity and safety.

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Remote ship operations are processes of supervising and administration of vessels from distance such that operators can collect vessels' operating information e.g. resource consumption or health status and administer a vessel to perform certain tasks remotely. Porathe et al. [1] explains that an unmanned vessel (no humans on-board) can be under remote control from a shore control center (SCC), while an autonomous vessel navigates based on the automated software system such that the vessel is being monitored by a shore control center (SCC) or from other places (e.g. a mooring supervisor or a pilot vessel). However, an autonomous vessel does not have to be unmanned and can consist of service crews, whereas the engine control room or the bridge is unmanned.

Although the remote ship concept attempts to improve efficiency of ship operations, it increases complexity of operations due to unknown dependencies and interactions of components. These unknown dependencies and interactions may hinder performance improvements or acceptability of new approaches. The current forum for Autonomous ships focuses on the technological aspect, whereas the social aspect is also a determinative factor in a system. In the context of automated environment, achieving an optimal level of system performance does not depend solely on possible improvements to technological components, but also by recognizing human interactions with an automated object [2]. Hence, numerous studies has attempted to identify human interactions in automated systems. For example, Sanchez presented a conceptual model of human-automation interactions comprising most of the well-established relationships for a generic automated environment [2].

However, the earlier models of human-automation interactions are generic and cannot completely fit into remote ship operation environment. One of the major challenges of remote ship operations is that human interaction, particularly human-machine and human-human interactions impose unpredicted behaviors. Therefore, analyzing the social aspect, particularly human interactions can maximize the system performance. According to the definition of remote operations, one important challenge is to consider human in the loop in remote ship operations. Therefore, the general aim is to consider human as a critical part of remote ship operations.

This paper presents a human interaction framework in the remote ship operations domain, in order to maximize system performance by minimizing conflicting operations. The proposed framework identifies human interactions in remote control centers as well as the main differences between remote and non-remote ship operations. The current study employs the human system integration (HSI) approach

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to assess human as a key component in remote ship operations. HSI provides an appropriate approach to improve the performance, reducing errors and making systems more error tolerant by considering human as an important element in the system. Considering human as an integrated part of the system result in greater knowledge gain about human so that this knowledge can be utilized in all system engineering phases such as planning and design. Hence, the theoretical background was investigated to extract information by performing coding analysis of collected data. Furthermore, the similar system analysis technique was employed and consequently collected data analyzed using coding process.

The rest of the paper is organized as follows: the definition of remote ship operations, human systems integration (HSI), and human factor engineering appear in Section II. Research methodology including HSI approach, HFE, and similar system analysis techniques as well as interviews' procedures and coding process of literature are presented in Section III. Section IV presents the proposed human interaction framework. Section V discusses the proposed framework and its implications for remote ship operations. Finally, Section VI concludes human interactions assessment in remote ship operations with regard to the proposed framework and proposes future research.

II. General Background

In remote ship operations (or teleoperations), an object is operated from a distance location such that there is no direct human sensory contact to it. Today operators use sensors and different technical methods to obtain information with regard to remotely operated objects and their environment. In hazardous and safety critical environment, remote operations are used to raise the human operators' safety and the economic efficiency of work. Remote operations can enhance work comfort, provide more pleasant and safer work environment by reducing dirt, tremble, extreme temperatures, noise, radiation, or other issues caused by the machines or their surroundings. Indeed, a large amount of different remote operation applications have already been developed, from remote mining [3] to remote space operations [4].

In the case of nautical vessels, remote operations imply different aspects based on the vessel types. In one aspect, it has been assumed that the vessel could be unmanned and remotely controlled and monitored during the trans-oceanic phases of the voyage [5]. Based on this scenario, the remote operator would not see the vessel directly but would monitor the vessel through the satellite connection. The U.S. Navy has illustrated the use of unmanned vessels such that operated side by side with manned vessels [6]. Indeed, the autonomous vessels can be controlled from larger vessels or on land centers via satellite connections and from shore control centers (SCCs) [7].

According to Porathe et al. [5], there are three main classifications of control for autonomous ships. First, indirect control which refers to updating the voyage plan during the voyages. Second, direct control which refers to ordering particular manoeuvres e.g., giving way for officials in a rescue operation. Third, situation handling that refers to bypassing the autonomous systems, in this situation, a remote operator would control the rudder and thrusters directly. It is notable to know that the unmanned ship is not the same as the autonomous ship. Porathe et al. [1] explain these two concepts as follows:

- " *An autonomous ship is navigating and making evasive maneuvers based on an automated software system. The system and the ship are under constant monitoring by a Shore Control Center (SCC). An autonomous ship does not have to be unmanned but can contain maintenance or service crews, while the bridge and/or the engine control room is unmanned*".
- " *An unmanned ship is a ship with no humans on-board. An unmanned ship does not have to be autonomous; it can be under autonomous control but it can also be under remote control from a Shore Control Center, or from other places (e.g., a pilot or tug boat or a mooring supervisor)*".

Although most visions for unmanned shipping substantially use of autonomous systems are often completed by human remote control and supervision, this means that there are several levels of autonomy [8]. According to the Sheridan's model [9], there are 10 levels of autonomy such that in the lowest level, autonomous systems only advise and help, while at the highest autonomous level, the system decides everything and override and replace human actions and decision making. Table 1 presents Sheridan's classification for different levels of autonomy.

TABLE I
LEVELS OF AUTONOMOUS - SHERIDAN'S MODEL

1	Computer offers no assistance and human must do all
2	Computer offers a complete set of action alternatives
3	Computer narrows the selection down to a few
4	Computer suggests a solution
5	Computer executes that suggestion if the human approves
6	Computer allows human some time to veto before automatic execution
7	Computer executes automatically, then necessarily informs human
8	Computer informs human after execution if only asked
9	Computer informs human after automatic acts only if it decides to
10	Computer decides everything and acts autonomously, ignoring the human

Regarding human interactions in the remote ship operations, human systems integration (HSI) derives from a simple fact that in work environment, there are some types of interactions between humans and everything in the environment, consisting of both hardware and software. [10]. INCOSE describes HSI as the interdisciplinary method and management processes for integrating consideration of human across and within all system components; it is an essential enabler to practices of systems engineering [11]. There is no generic terminology for HSI so that the HSI concept is applied at the different level in different ways. For instance, designers at NASA perform HSI in a particular way, whereas integrators at Boeing and Airbus perform HSI differently [10].

On the other hand, human factor engineering (HFE) specifies human capabilities and constraints and applies this knowledge to engineered hardware and software system's design. It is also known as usability engineering, cognitive ergonomics, or user-centered design. HFE is the application of knowledge about human strengths and weaknesses to the design of technology [12], and it promotes successful human-machine integration [10]. It is noticeable that Gordon Vos, in the NASA HSI presentation, explained human factor engineering (HFE) as a part of human system integration (HSI) [13].

III. Methodology

The current paper involves analyzing literature and employing human system integration (HSI) in order to develop a human interactions framework for remote ship operations. In the context of HSI, this study employed a human factor engineering (HFE) technique named similar system analysis, which comprises observation and interviews. Furthermore, the theoretical background was investigated to extract information through coding analysis of collected data.

Literature regarding human-automation interactions was analyzed to identify the human-remote controlled system interactions. In addition, the similar system analysis was applied to human factors (HF) in order to examine previous systems (old systems) or in use systems; the knowledge gained from this examination will be useful for the new systems [14]. This implies that similar system analysis was an optimal technique in order to identify human interactions and fundamental differences between remote and non-remote ship operations.

The purpose of the similar system analysis technique is to gain best practices and lessons learned in order to be used during system design. The inputs for this technique comprise structured observations, interviews, questionnaires, activity analysis, maintenance records, accident/incident reports, and training records [14]. In this study, the similar system analysis technique comprises interviews and observation. Non-participant observation, where the researcher is an outsider of the group under study, was performed by watching from a distance and taking field notes [15]. Three hours of observation was conducted in a simulated environment, where two learning assistants of simulators operated two different nautical operations between two ports in simulators. The simulated environment assumed as a remote-control center, in which all operation activities of the vessels were controlled remotely.

The semi-structured interview guide comprised 17 questions, which were inspired from theoretical background. Convenience sampling was employed by selecting conveniently available sampling units. Interview invitation was sent to five researchers at the Engineering Faculty in a Norwegian University, and four of them, one assistant professor, one project manager and two researchers, constitute the interviewed sample.

Interviews and observation transcripts were used to classify and identify the collected data. During the data analysis, coding process was used to analyze the theoretical data (literature review) as well as data collected by the similar system technique (observation and interviews).

The coding analysis of the theoretical data was conducted by two authors. Initially, the first author performed the coding process, then the findings were shared with the other author who performed the coding process as well. The first author then compared and decided the final codes. A combination of descriptive and in-vivo coding approaches was selected. In the descriptive coding, codes assign labels to data in a word or short phrases, while in in-vivo coding, which is one of the most important qualitative coding methods, codes are short phrases or words from the data or from the own language of participants in the data record [16].

Due to lack of available remote ship control centers, a simulator environment assumed as a remote control center. This was an obstacle regarding verifying the approaches experimentally. In addition, due to lack of available experts in using remote ship control centers, only four interviews were conducted, which could be counted as another limitation of this study.

IV. Human Interactions Framework

Building remotely operated ships are technologically achievable now, but it does not guarantee that remote operations will improve human interactions with machine. Hence, human interactions analysis in form of a framework in the remote ship operations context is an optimal solution to maximize system performance.

Various conceptual models are attempted to identify key factors, which affect human behavior in an automated environment. Rilley [17] and Dzindolet et al. [18], [19] represented two comprehensive and fundamental models in this field. In addition, Sanchez [2] provided a conceptual model of human-automated interactions in order to illustrate human behavior in an automated environment.

A conceptual human interactions framework in a remote control center, which comprises most of the well-established variables to date, was provided according to the human system integration (HSI) approach. Figure 1 presents the human-remote control system (RCS) interactions tailored for a remote control center; components of this model are highlighted by Riley [17], Dzindolet, Pierce, Beck, Dawe, and Anderson [19] and Sandchez [2]. It is notable that interactions in this model focus on human components based on the human factor interaction model. In Figure 1, human-machine and human-human interactions are classified by different colors using the following abbreviations:

- RCS: Remote control system(refers to use of remote control system)
- LOA: Level of automation
- (+): Positive relationship
- (-): Negative relationship
- (+, -): Both positive and negative relationship

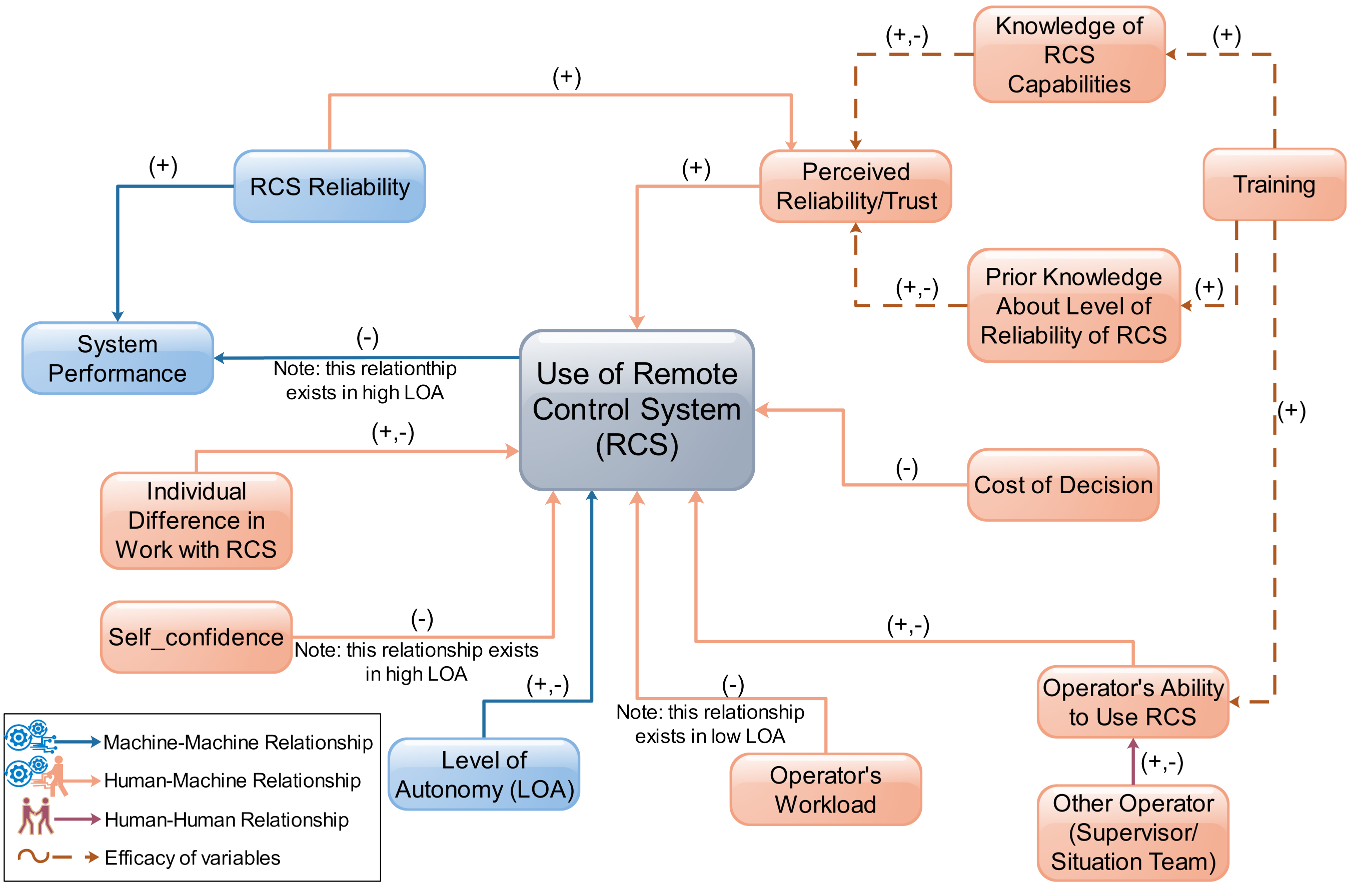

Fig. 1. The human interactions model for remote ship operations (inspired from Sanchez, (2009)).

Riley [17], described that how reliance (use of automation), machine accuracy and operator accuracy (automation reliability) influence system accuracy (overall system performance). The model of Dzindolet et al. combined 12 of 13 variables, which were reported by Riley, by grouping the variables into cognitive, social, and motivational processes, in order to provide an organized theme. The models from Riley and Dzindolet provide a fundamental and valuable framework for interactions and relationships in automated environments. However, both failed to consider some of the key variables such as levels of automation (LOA) and human's knowledge of the automation's capabilities[2], [19], [17].

Sanchez [2] introduced relationships in his human-automated interactions model, but did not consider the effect of some variables such as training and interactions between operators. In this respect, the current conceptual framework considers the effect of training programs on the prior knowledge about RCS and the level of reliability of RCS. On the other hand, training programs affect the ability of operators to use the RCS. These relationships are therefore introduced as efficacy variables. In addition, based on the organization of remote control centers, several operators interacting with each other (e.g., situation team, supervisor, and operators), another interaction between operators which is highlighted in the framework. This relationship affects the ability of operators to work with the RCS.

Numerous research has suggested a strong positive relationship among perceived reliability (trust) and automation use [2], [20], [21], [22], [23]. From the perspective of Sanchez [2], automation will be used more if human trust increases; in addition, the perceived reliability can be affected by prior knowledge about the level of reliability, knowledge of automation capabilities and automation reliability [2].

According to Sanchez's conceptual human-automated interactions model [2], there is a positive relationship between operator's workload (the amount of work which is imposed on operators) and the use of automated system. This relationship is, however, negative in a remote controlled environment. Our findings indicate that when operators in a remote control centers are imposed to too much information, the performance of the operators would decline.

There is a common definition of automation reliability in the field of human-automation interactions: "*the number of the correct operations divided by the total number of the operations which a task is automated*" [24]. It is argued that when the reliability of automation increases, an overall increase in the system performance is expected. However, high levels of automation reliability during extended periods of time can have an adverse effect on performance of human;

this refers a negative affect on the system performance. In this field, system performance mentions to the ability of human to behave and act as a backup system to the automation [25], [2].

In human-automation interactions, self-confidence is explained as" *anticipated performance during manual control*"[23]. According to Sanchez [2], It is striking that self-confidence is not a measure in numerous research, which has looked at lower LOA (level of autonomy). One reason for this is that self-confidence emerges in relation to tasks that can be entirely reallocated to the automation or can be conducted manually in their entirely. Some studies explain that benefits created by various LOA are related to the reliability of automation. This means that when the automation reliability is ideal (e.g., [26]), high LOA enhances entire performance compared to low LOA [2].

There are compelling evidences that clear awareness of individuals about entire reliability of an automated system influences their trust on the automation system [2], [27], [28], [29]. This indicates a relationship between prior knowledge about level of reliability and use of automated systems. On the other hand, human behavior in the automation field is significantly affected by the amount of available knowledge about the automation capabilities [30], [19], [31], [32], [33], [2].

In most of operational environments, there is a perceived cost, which is associated with decisions. Various studies suggest that human behavior in automated systems is probably a function of benefits associated with the perceived costs [2]. In addition, different studies explain that there are individual differences in the employed strategies to interact with the automated system. For instance, in studies with action implementation automation (e.g., [23], [17]), there is a significant difference in the employed strategies between the participants who have different conditions [2].

On the other hand, there are fundamental deferences between remote and non-remote operations, which may affect human interactions. According to our findings, fundamental differences between remote and non-remote operations can comprise high dependency on sensors in RCS, economic advantages of RCS, different command chain in SCC, lack of local knowledge in SCC, distance and latency in practical tasks in RCS, lack of sense of ship, communication challenges between SCC and ship, less information in SCC, high level of workload in RCS, difficulties of decision making in hazardous situation, limited situation awareness, boredom, safety of crew, less stress for operators and flexible working hours in remote operations.

The proposed framework provides relationships between variables in a remote controlled environment. Although the variables represents different human factors, their effect on the remote control systems are assumed to be equal. Nevertheless, the proposed framework can be utilized in order to present different human factors in remote controlled environments and gather knowledge about human. This knowledge can be used in conceptualization and design phases of remote control systems.

V. Discussion

Applying the HSI approach in a complex system facilitates assessment of human interactions. The knowledge of this assessment can be utilized to design a new system, which is more compatible with human capabilities and limitations. Indeed, assessment of human interactions in complex systems results in understanding the effect of human behavior on system operations attentively. In the field of remote ship operations, a vessel can be controlled remotely from another place e.g., a shore control center (SCC) so that human as operators are involved in remote-control systems (RCS). The present study develops a human interactions framework and presents challenges for remote-control systems in order to maximize the system performance by minimizing conflicting operations.

One of the main challenges of remote ship operations is understanding human behavior and developing human interaction models in a remote controlled environment. In this respect, the earlier human-automation interactions studies are generic with models that do not completely fit into the remote ship operation environment. This study employed human system integration (HSI) to consider human as a critical sub-system in remote control systems. A literature review and similar system analysis are used in order to develop a conceptual human interactions framework in the remote controlled environment (e.g., shore control centers). The framework identifies three types of relationships in a remote-control center comprising *(i)* human-machine; *(ii)* human-human; *(iii)* machine-machine interactions. The proposed framework comprises well-established variables in an automated environment. However, the framework is updated and tailored in order to fit in to remote control centers by considering the effect of training programs and interaction between operators in remote control centers. Specific training programs affect the operators' knowledge about capabilities and perceived level of reliability about RCS. These two variables are considered as efficacy variables, which affect the perceived reliability (trust) of operators about remote control centers. Despite the earlier models of automated-human interactions, the proposed framework presents a negative relationship between the workload and the use of RCS.

It is clear that when the type of technology changes, the human-human and human-machine interactions change consequently. For instance, operation of ships in remote-control centers are highly dependent on sensors and act mostly based on sensor information. Therefore human-sensor interactions are more highlighted in remote operations than in non-remote operations. However, limited situation awareness or difficulties of decision making in a hazardous situation (e.g., unpredictable malfunctioning or failure of sensors in hazardous situation) in RCC due to the lack of local sense or ship sense, can significantly change human interactions in remote centers. In non-remote operations (on-board), crew or engineers physically sense the ship and make decisions based on local and tacit knowledge, but in remote-control centers, decision making relies highly on sensor information and the capability of operators. On the other hand, working in SCCs brings better social life for operators, because they work in shifts and do not need to stay on-board. However, operators in remote-control centers may experience boredom due to sitting on a chair, often in a dark room, for consecutive hours. In addition, lower level of stress and feeling safe can provide a better workplace for operators to perform more efficiently. In a remote-control center, there is limited information (limited situation awareness), but a higher level of operator's workload, which may affect the process of decision making and interactions.

Furthermore, controlling operations of several ships in one control center may impose single point of failure, which may affect several ships. Indeed, any failure in remote control centers may affect the operations of several ships so that a secondary control center should be devised in case of any failure (e.g., geographical disaster or connectivity problem) in the remote control center. This implies that considering additional human factors in the proposed framework provide greater insight into human interactions for remote ship operations and consequently facilitates performance improvement actions. As the current paper employed the HSI approach to consider human in the loop for remote ship operations, designers and engineers could obtain structured information about human for all phases of design. In addition, the proposed framework facilitates understanding, predicts human behavior in remote control centers and consider human as a critical sub-system in remote ship operations.

VI. Conclusion

The remote ship concept is pronounced to improve efficiency of ship operations, but, due to unknown interactions and relationships of components, it also increases the complexity of such operations. Ignoring human behavior as a critical sub-system in a remote controlled environment can degrade the overall performance. However, this represents a gap in conceptualization and operations of remote ship environment because of ignoring human as a critical subsystem. The current paper employed the human system integration (HSI) approach in order to consider human as a sub-system. In this respect, a literature review and a human factor engineering technique (HFE) named similar system analysis were utilized to collect data. Accordingly a coding process was performed to analyze the data. The proposed framework provides productive knowledge to improve the remote-control system design. It also implies that human system integration (HSI) is a proper approach to assess and analyze human factor challenges and interactions in remote ship operations. The proposed framework updates the earlier models of human-automated interactions and is tailored to fit in to the context of remote ship control centers. It indicates that training and interactions between operators, in addition to earlier human interactions in an automated environment, provide other types of human interactions in remote control centers. As a result, the negative relationship between the workload and the use of RCS is highlighted. Furthermore, the current study mentions differences between remote and non-remote operations, which provide greater insight into human interactions for remote ship operations and consequently facilitates performance improvement actions. The gained knowledge could be used by designers and engineers in all phases of remote control centers design.

VII. Future work

This paper proposed a conceptual human interaction framework in order to facilitate performance improvement actions in remote control centers. Although the proposed framework is built upon grounded assumptions and literature, the framework has not been experimented in control centers. In a follow-up research, the proposed framework will be experimented in order to verify the interactions in practice. In addition, future studies will focus on more quantitative experiments in simulated environments in order to identify unknown problems and other types of human interactions.

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