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SPECIAL ISSUE ARTICLE

Exploring the effects of automation malfunction on team communication and coordination in ships' engine rooms

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Abstract

Automation malfunctions within complex socio-technical systems reserve the potential to significantly affect human performance. In the context of maritime operations, varying consequences of automation malfunction on human performance can be observed. This study introduced a two-step research framework to examine the repercussions of such malfunctions, particularly those related to communication and coordination among human teams in ship engine rooms. Initially, a qualitative semi-structured interview was conducted with seven professional marine engineers to explore the potential impact of hypothetical automation malfunction on team communication. Subsequently, a quantitative survey involving 32 professional marine engineers employed coordination demand analysis (CDA) to scrutinize changes in team coordination resulting from malfunction. The findings indicate that an automation malfunction within an engine room can precipitate an abrupt overload of the socio-technical system. This can significantly increase communication frequency among engineers, particularly in relation to the physical and organizational aspects of the environment. Furthermore, the study highlights the influence of disparate levels of expertise among team members on coordination demands. A positive correlation was discovered between differences in expertise and increased coordination demands within a team. These insights underscore the necessity for future research on human–automation interaction, specifically focusing on individual differences and nontechnical skills.

KEYWORDS
automation, human performance, socio-technical systems, team communication, team coordination

1 | INTRODUCTION

Socio-technical systems encompass intricate interactions between people, technologies, and their work environment, particularly in safety-critical domains such as aviation, healthcare, and nuclear power.[1–3] The maritime industry is considered a safety-critical domain, while maritime operational environments onboard merchant ships can be characterized as complex socio-technical systems.[2] The dynamic interaction among seafarers, automated equipment, and external elements such as weather, organizational procedures, and work practices constitutes the socio-technical system of a ship. Automated technologies are currently being employed in maritime socio-technical systems to enhance safety and maximize efficiency. The integration of automation in shipping operations is exemplified by the deployment of tools such as an automatic radar plotting aid (ARPA) and electronic chart display and information system (ECDIS) for navigation, as well as local area network (LAN) connected computer systems to support various routine tasks, including cargo handling, ballast operations, and engine room monitoring, which were previously managed manually. Incorporating automation into such an intricate environment influences human performance, situational awareness, and workload.[4–6]

While automated systems excel in routine tasks, their malfunctions can result in systemic, catastrophic outcomes.[7,8] Beyond the evident improvements in efficiency and safety from automation, issues such as skill deterioration, overreliance, and complacency frequently emerge in complex human–automation interactions.[9,10] This is especially seen in places such as ships' engine rooms, where time-sensitive tasks depend on varying levels of automated equipment, all of which can increase the chances of automation malfunction in engine room operations.[11] Existing literature has inadequately addressed the consequences of such automation malfunctions in maritime socio-technical systems. This study examined the dynamics of teamwork in the context of automation malfunctions in the socio-technical system of a ship's engine room. Specifically, it focused on the role of communication and coordination in facilitating effective teamwork in such situations.

Team communication refers to the interactions and exchange of information among team members,[12] while team coordination involves the use of strategies and behavior patterns to align the actions, knowledge, and objectives of interdependent members.[13] Effective teamwork, vital for achieving collective aims in intricate systems, hinges on communication, coordination, cooperation, and shared mental models.[14,15] Within a ship's engine room mimicking a closed socio-technical system, human and automated processes synergistically operate—automation addresses repetitive and high-precision tasks, while humans handle critical thinking and problem solving. Human adaptability provides the flexibility to accommodate changing situations, whereas automation operates based on predefined inputs. This interplay becomes especially pertinent when automation fails, affecting human–human or human–machine collaboration. The attributes of ship engine rooms closely mirror those of the control room operators in highly automated systems, whether in the process industry, nuclear power plants, or similar domains. Hence, understanding human interactions in complex environments, such as in engine rooms, and their responses to automation malfunctions is crucial for risk minimization and efficient ship operations.

This study aims to investigate whether malfunctioning in automated processes has any consequences on human teams regarding communication and coordination patterns in a socio-technical context. To this end, we posed two research questions (RQs):

> **RQ1.** What are the effects of automation malfunctions on **team communication** in a ship engine room?

> **RQ2.** How does automation malfunction affect the overall **team coordination** in an engine room?

As the scope of RQ1 is more qualitative, the following hypothesis is proposed for RQ2:

Team coordination significantly increases in the event of automation malfunction.

The null hypothesis (H_0) and alternate hypothesis (H_a) for RQ2 are formed as follows:

> **H0.** There is no difference in team coordination between the normal operation scenario and automation malfunction scenario.

> **Ha.** There will be a significant difference in team coordination between the normal operation scenario and automation malfunction scenario.

2 | BACKGROUND

The integration of automation in various safety-critical domains has revolutionized operational efficiency. However, the dependence on automation has raised concerns regarding its potential impact on human performance, especially when malfunctions occur.[16] Automation plays a pivotal role in maritime operations, assisting in navigational and engine room functions; however, its implications for human–machine interaction remain underrepresented in research. Moreover, the maritime environment, which is inherently complex and demanding, often requires a high level of teamwork, coordination, and communication among crew members.[17] In this section, literature excerpts are analyzed to elucidate the relationship between automation malfunctions and human performance, focusing on team communication and coordination in maritime operations.

2.1 | Automation, human performance, and communication

Modern automation originated in the automobile industry and has since expanded to various sectors with the goal of reducing workload and human error and enhancing safety.[18,19] Automation has evolved from supervisory technology to a bidirectional cooperating medium between humans and machines as the systems become more sophisticated and complex.[20] This evolution has rendered the reliability of automated systems dependent on reliable human performance. The benefits of automation include improved safety, reliability, economy, comfort, workload management, and communication.[21–23] However, operational problems within the workplace do not necessarily reduce with the inclusion of automation, as no process is fail-safe.[24] The literature suggest that poorly designed and integrated automation can decrease system performance by increasing workload and decreasing situational awareness, leading to accidents in extreme scenarios.[21,25,26] Additionally, an overreliance on automation can create conditions where operators are "out-of-the-loop", reducing their ability to make fully informed decisions in situations where manual control takeover is required due to any malfunction (see Figure 1).[27,28]

There are certain aspects of human interaction and cooperation that technology may not be able to replicate fully; thus, some tasks that require collaboration cannot be completely automated. In the context of human–automation interaction, delegation of tasks between humans and automated equipment has been found to be useful, with the control of automation rotating among different system agents to provide flexibility for operators in managing tasks across multiple levels of communication. Miller and Parasuraman (2007) noted that such delegations allow for better task management and communication across different levels.[29] Furthermore, the inclusion of automation in workplace systems has led to changes in communication techniques and the frequency among human agents. For instance, Kaber et al. (2001) found that the use of automation affects the frequency of nonverbal information exchanges among human operators.[30] Optimum human–human and human–machine interactions are crucial, particularly in situations where independent individual tasks may become interdependent team tasks. Communication and coordination among team members are crucial factors for ensuring optimum task efficiency in such situations.

2.2 | Evolution of automation in maritime operations

The aviation industry pioneered automated operations,[31] which led to increased safety, efficiency, and productivity, while reducing operating costs.[32] This prompted the maritime industry to adopt automation technologies for sea- and shore-based operations. Navigation officers typically handle route planning and cargo management, whereas engineering officers and ratings focus on operation, monitoring, troubleshooting, and maintenance.[33] The engine control room (ECR) is the central command for engine room operations, with engineer officers on watch supervision and maintenance of automated processes.[34]

Early automation ideas for the maritime domain aimed to ease navigation operations using various aids and systems.[35] The application of automation has expanded throughout the latter half of the 20th century, leading to innovations such as automatic routing[36] and unmanned ships.[37–39] Automation has traditionally been used by ship crews to support decision-making by accumulating extensive information about the ship and the environment and integrating different subsystems to enhance ship control.[5,6] Consequently, the required crew size on board has significantly decreased over the past few decades.[5,6] Recent discussions related to the integration of automation technology in maritime operations go beyond mere automated systems onboard and extend toward incorporating artificial intelligence and deep learning algorithms for autonomous navigation,[40] predictive maintenance, big data fusion in logistics operations,[41] as well as human–autonomy collaboration[42,43] in various maritime operations.

2.3 | Teamwork in socio-technical systems

Teamwork involves collaboration and interdependence between individuals working toward a common goal.[44,45] Effective collaboration necessitates the integration of team leadership, mutual performance monitoring, backup behavior, adaptability, and team orientation, supported by coordinating mechanisms such as shared mental models, closed-loop communication, and mutual trust.[46,47] Therefore, communication is a crucial aspect of successful teamwork, particularly in

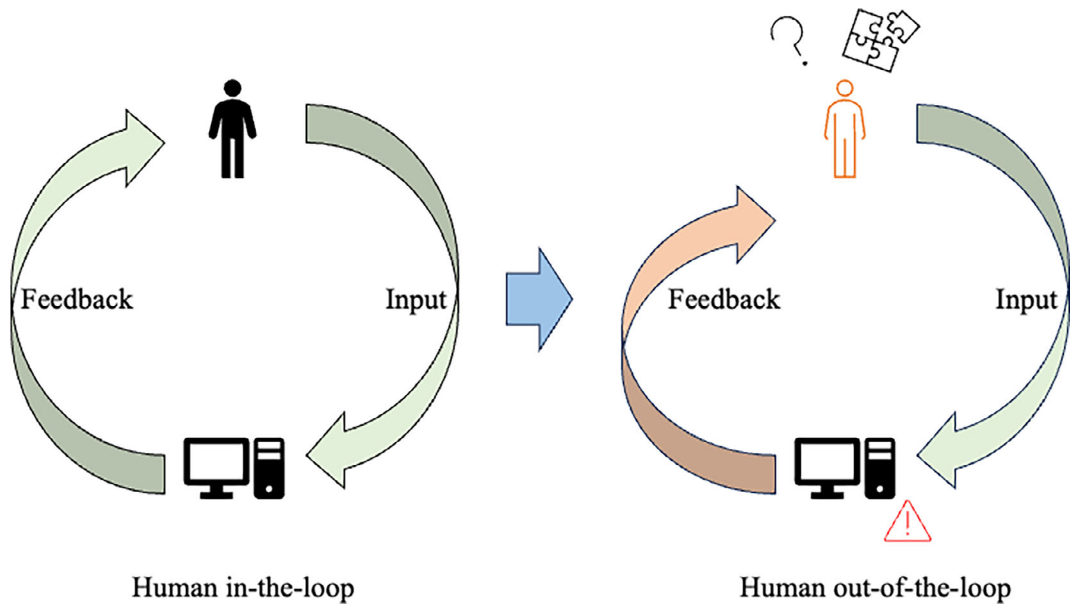

FIGURE 1 Human out-of-the-loop syndrome during automation malfunction.

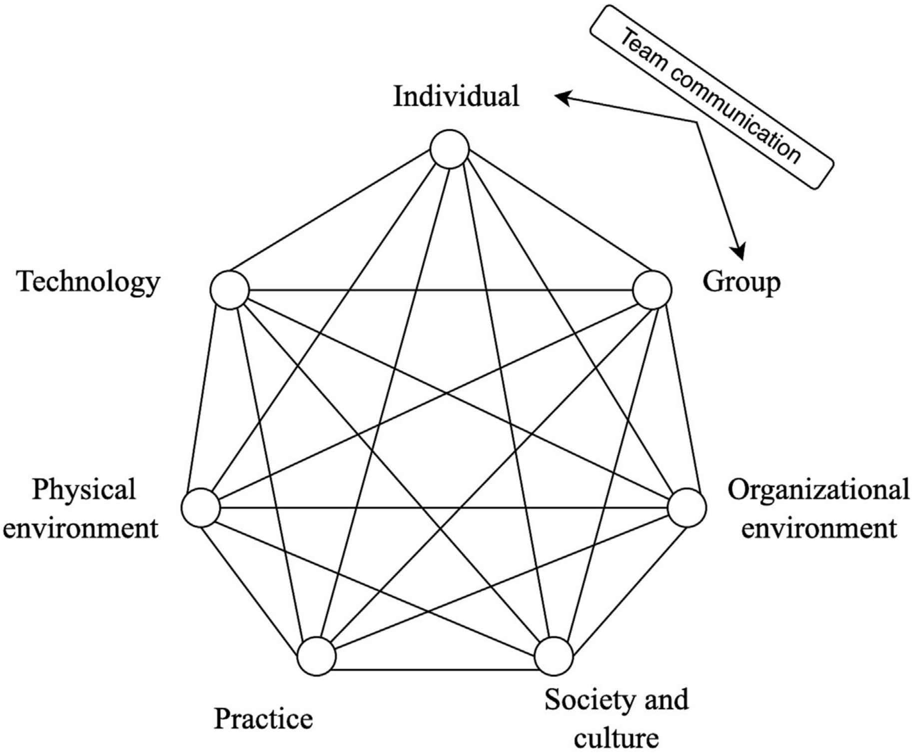

FIGURE 2 The "Septigon model" for socio-technical systems adapted from Koester (2007).[2]

high-stress environments.[48] The core definition of communication is understanding between individuals,[49] and in socio-technical systems, it is represented by the interaction between "individual" and "group" nodes in the Septigon model (see Figure 2).[2,3] Communication is particularly important in abnormal situations and is closely linked to safety.

However, the impact of automation on communication and coordination remains inconclusive, with some studies suggesting improvements (e.g., Wise et al., 1992 for communication and Clothier,[50] 1991 for coordination),[51] while others show deterioration (e.g., Costley et al., 1989 for communication[52] and Bowers et al., 1993 for coordination).[53] As automation becomes more prevalent in maritime domain, further research is needed to understand its effects on team communication and coordination in maritime socio-technical systems.

3 | METHODS

3.1 | Research design

To examine the impact of automation malfunctions on team communication and coordination within ship engine rooms, this study utilized both qualitative and quantitative approaches. Morse (2016) characterized qualitative methods for capturing experience, and quantitative methods for quantifying aspects of these experiences.[54] In this context, a qualitative approach is proposed to elucidate variations in communication and teamwork, and a quantitative method is proposed to gauge shifts in team coordination due to automation malfunction. Using cognitive work analysis (CWA), qualitative semi-structured interviews were conducted to explore shifts in "team communication" within the engine room's socio-technical context. This was followed by a quantitative coordination demand analysis (CDA) survey to assess potential changes in "team coordination" during automation malfunctions. This study employs a two-step methodology (see Figure 3).

- A CWA involving semi-structured interviews was conducted to address RQ1.
- A CDA involving a quantitative survey was performed for hypothesis testing of RQ2 in this study.

3.1.1 | Cognitive work analysis and interviews for RQ1

This study employs a cognitive work analysis (CWA) framework to investigate team communication among engineers in a ship's engine room, particularly in the context of automation malfunction situations. Although established checklists and processes exist, marine engineers use alternate communication techniques to complete their work more quickly and adaptably.[55] In this study, we delineated a specific case boundary focused on ship maneuvering operations during which engine room crews maintained heightened alertness. Data were collected through semi-structured interviews, enabling a bottom-up approach that encompassed both best practices and standard operating procedures. Subsequently, a cross-case analysis was conducted to evaluate the gathered data. Participants recounted their actions during both routine and malfunctioning events experienced during their sailing careers. Interviewees were asked the following questions[56]:

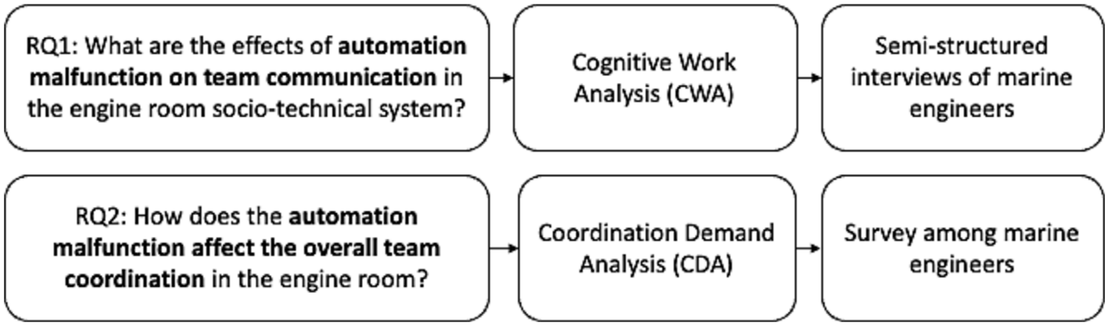

FIGURE 3 Conceptual framework for the research design of this study.

TABLE 1 Demographics of interview participants.

Description	Value
No. of respondents	07
Average age	29.5 years (SD = 5.8)
Average work experience	5.6 years (SD = 6.45)
Management-level engineers [Class-1, Class-2 (I/2, III/2, III/3; STCW'2010]	02
Operational-level engineers [Class-3 (I/2, III/1; STCW'2010)]	05

- How is crew organization structured in the engine room during maneuvering?
- What are the responsibilities of engineers during ship maneuvers?
- How does the crew engage in communication during routine operation?
- What protocols or procedures do engineers adhere to during ship maneuvers?
- How do the aforementioned elements change during an automation malfunction?

Seven marine engineers with Certificate of Competency (CoC) employed in different ranks on merchant ships were interviewed on a voluntary basis without any incentives (see Table 1). The project proposal and data collection methods were approved by the Norwegian Center for Research Data (NSD) (approval number: 134370). All interviews were conducted online, considering the practicality of reaching out to active seafarers. Participants were sourced from professional groups and academic affiliations via purposive sampling, with data subsequently anonymized during processing.

3.1.2 | Qualitative data analysis

Semi-structured interviews were analyzed to extract information on several dimensions, including crew organization, tasks and duties, automation malfunction instances, remedial actions, communication frequency and techniques, manpower requirements, formal procedures, and additional information. The analysis involved descriptive coding, analytic memoing, assertion and proposition development, and a cross-case analysis.[57] Assertions were made for each topic to summarize the statements, and jotted notes from the interviews were used in proposition development. Cross-case analysis was used to explore the differences between the normal and automation malfunction scenarios (see Figure 4).

3.1.3 | Coordination demand analysis for RQ2

This study used CDA, a quantitative method, to measure the changes in coordination demand between the two scenarios among human teams (RQ2). The CDA identifies teamwork activities and rates them based on coordination demands in several dimensions (e.g., communication, situational awareness, decision-making, mission analysis, leadership, adaptability, and assertiveness) excluding individual tasks. For example, in a specific scenario, all required tasks are first divided into different subtasks, which can be categorized as "individual tasks" and "team tasks" based on the nature of the scenario and expert inputs. The number of "individual tasks" and "team tasks" may change based on the scenario; hence, the percentage of team task in a particular scenario may also change. Similarly, the coordination demand for each "team task" is subjected to change as communication frequency and the level of situational awareness etc. may also vary depending on the scenario. Expert ratings can be used to determine the level of coordination in each "team task" on different dimensions such as communication, situational awareness, decision-making, mission analysis, leadership, adaptability, and assertiveness. Individual tasks were not considered, because they did not require any team coordination. Consequently, it is possible to identify the required level of coordination (as a percentage) as well as the any change in the coordination demand in extraordinary situations, that is, during automation malfunction. In addition, CDA analysis is frequently used to answer the "what?" and "how?" during the critical event analysis of teamwork in socio-technical systems.[58] Therefore, the CDA is a unique and effective method for estimating the magnitude of team coordination in team tasks in a specific scenario.

Summary statistics are derived from expert ratings to calculate "total teamwork requirement" for each scenario, which is then

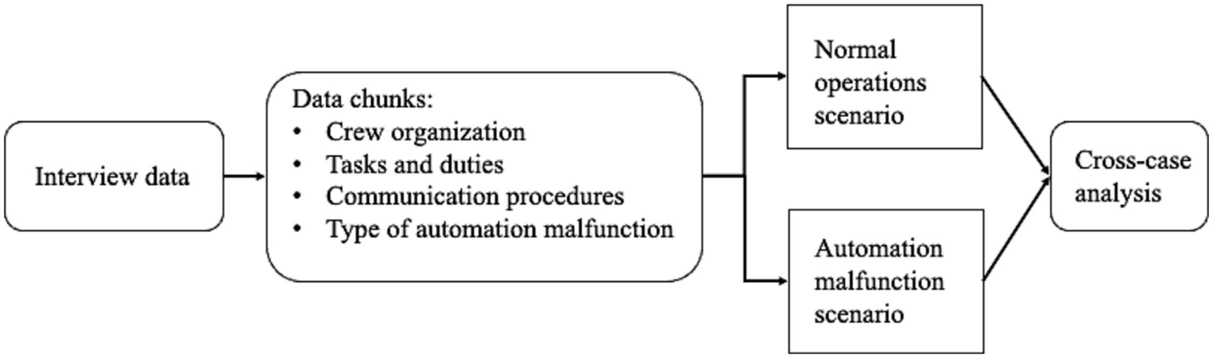

FIGURE 4 Conceptual framework of qualitative data analysis.

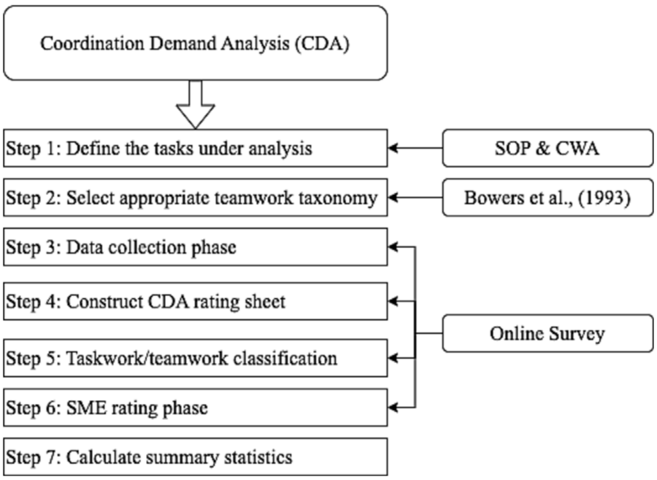

FIGURE 5 Conceptual framework of CDA for the current study.[59,60]

compared to determine any change in coordination demand between the scenarios. A quantitative survey was used following a modified framework,[59,60] which is detailed in Figure 5.

Thirteen tasks were identified through semi-structured interviews with CWA. These tasks were weighted for coordination demand across various teamwork dimensions, such as communication, situational awareness, decision-making, mission analysis, leadership, adaptability, and assertiveness. Marine engineers completed a Coordination Demand Questionnaire (CDQ) for a malfunction in the automated three-way valve of the jacket water-cooling system, which defined the boundary conditions of the CDQ. Each task was rated as “low,” “medium,” or “high” high based on two scenarios: normal operation and automation malfunction. A total of 34 respondents completed the survey, and two incomplete submissions were excluded from the analysis (see Table 2).

TABLE 2 Demographics of survey participants.

Description	Value
No. of respondents	32
Average work experience	6.08 years (SD = 6.29 years)
Management-level engineers [Class-1, Class-2 (I/2, III/2, III/3; STCW'2010]	07
Operational-level engineers [Class-3 (I/2, III/1; STCW'2010)]	25

3.1.4 | Quantitative data analysis

The survey data included CDA ratings of “team tasks” on various coordination dimensions. For each response, a “CDA summary statistics” was created, displaying summary items such as total taskwork, total teamwork, and coordination measures for two scenarios: a normal operation scenario and an automation malfunction scenario (see Figure 6). The “total teamwork required” in each summary represented the subjective coordination demand of the scenario for the respondent. Data analysis was performed using IBM SPSS (version 26) software. A Shapiro–Wilk test indicated the non-normality of the data; therefore, a nonparametric Wilcoxon signed rank test with a 95% confidence interval ($\alpha = 0.05$) was used, as appropriate for sample sizes of $N > 15$.[61]

4 | RESULTS

4.1 | Effects of automation malfunction on team communication

Qualitative data obtained through semi-structured interviews with marine engineers shed light on the socio-technical structure in the engine room and the impact of automation malfunctions on team communication. The interview participants were probed for their input on different aspects of team communication during an automated malfunction scenario. Experts' views on the size and involvement of the crew in their day-to-day operations, related standard procedures, different communication techniques used, and associated disruptions during automation malfunction events were identified.

Based on the analysis of the interviews, “engine room watchkeeping” appeared to be teamwork, with the Chief Engineer or

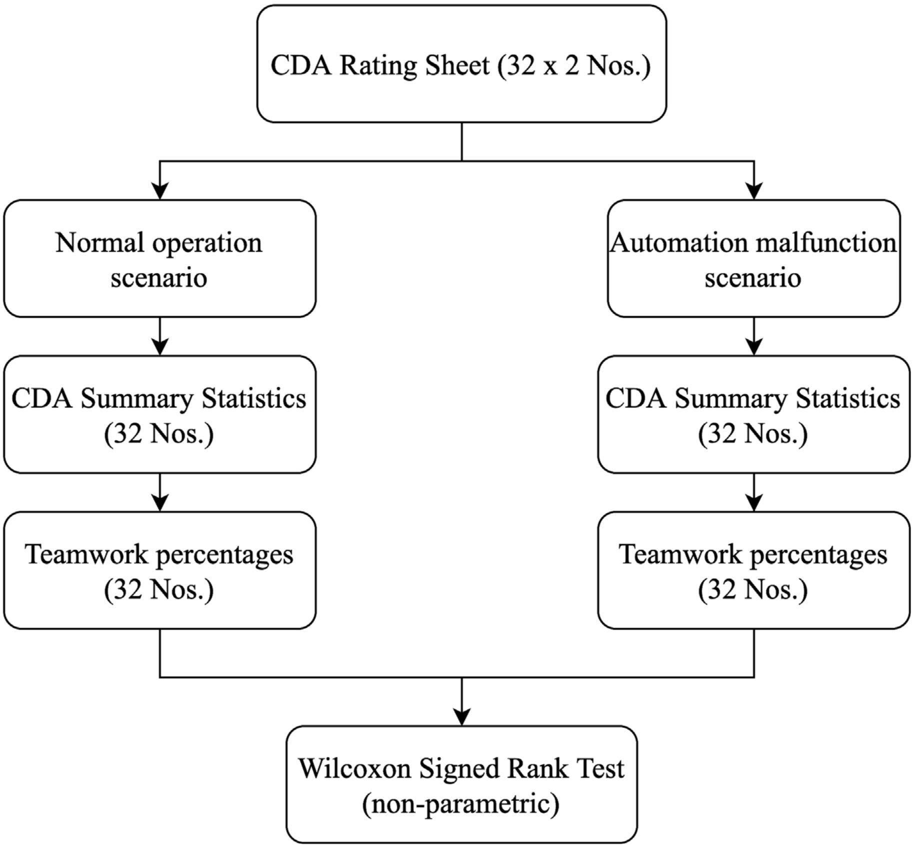

FIGURE 6 Conceptual framework of quantitative data analysis.

Second Engineer handling management tasks, while the Engineer Officer on Watch (EOOW) managed operational and watchkeeping responsibilities. The Unmanned Machinery Space (UMS) operation mode involved specific practices during night watches, with the main watchkeeper remains "on-call" rather than being physically present in the engine room. In this context, Participant 1 underlined:

> We had several instances of automation malfunction in the engine room. Sometimes, there is a fault in the main engine jacket water controller or boiler cascade tank temperature sensor, and sometimes the automatic drain solenoid valve of the air compressor would not work. The 2nd engineer oversaw the main engine, the 3rd engineer was in charge of the boiler, and the 4th engineer was responsible for the air compressor. So, the respective engineers, even off-duty, were called if the duty engineer could not solve the problem.

On a similar theme, Participant 4 highlighted the "*crew efficiency*" while Participant 7 outlined the "*leadership and management skills*" of the chief engineer and the second engineer (management-level engineers) as important catalysts during the mitigation of automation malfunction situations. Additional tasks included extended monitoring and the manual operation of processes that would otherwise have been automatically operated. In most cases, engineers reported that automatic control was turned into manual mode wherever situation permitted, to continue critical operation until the problem was fully rectified at the earliest possible opportunity. In that case, team communication among the engine room crew members increased, as reported by Participants 1, 2, 3, and 4 in consensus. One of them stated:

> The frequency of communication among crew increased since the additional watchkeeper was engaged in the manual operation of the otherwise automatically operated valve and the EOOW had to call or signal him every time a change in the valve's position is required.

The lack of standard procedures has been reported during automation malfunction in the engine room as Participant 2 outlined:

> Therefore, checklists are important in this regard. Experience does not always cover required actions. Some actions depended on the company's standards. We do not usually have a separate checklist for automated malfunctions. However, because automation failure means extreme emergency, we use a common emergency checklist instead.

In a similar context Participant 6 informed:

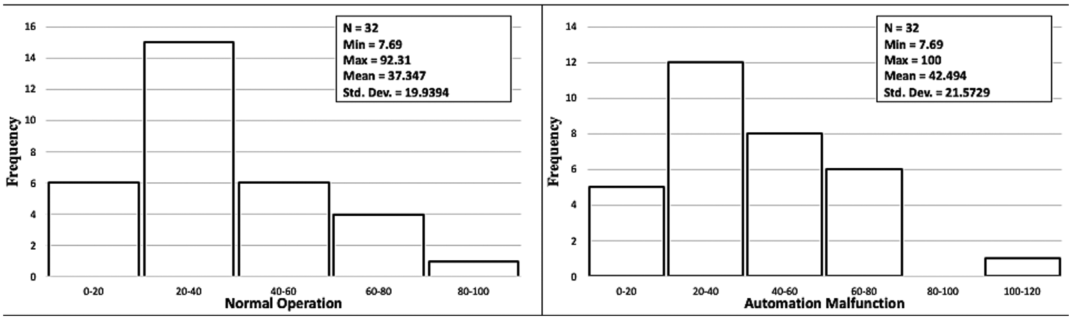

FIGURE 7 Graph presentation of teamwork percentages; (A) normal operation statistics and (B) automation malfunction statistics.

> We had an emergency checklist available, but since the situation escalated quickly, we didn't have time to follow any checklist.

The analysis revealed that opinions varied regarding automation malfunctions in the engine room, with some considering them extreme emergencies, whereas others reported mere panic events for engineers on duty. The issue of out-of-loop performance owing to automation malfunction has not been unanimously confirmed. Some operational engineers have reported an increase in mental and physical workloads during these situations. In terms of interpersonal communication, standard techniques, such as audible electric bells, walkie-talkies, and telephones, are commonly used. Verbal exchanges and hand gestures are frequently used in team communication. However, concerns have been raised over the use of walkie-talkies owing to excessive noise in the engine room environment. Nonverbal communication has also been reported to be more frequent in malfunctioning scenarios. Though the expert responses were thematically similar for the probed interview questions, the individual responses highlighted a few unique areas necessitating careful interpretation that fits the context.

5 | EFFECT OF AUTOMATION MALFUNCTION ON TEAM COORDINATION

It was hypothesized that team coordination would increase during the automation malfunction scenario compared with normal operations. The Wilcoxon signed rank test was used to analyze the total teamwork requirement (in percentage %) in both normal and malfunction scenarios, and the results showed a significant difference between the two scenarios with a medium effect size ($N = 32$, $Z = -3.204$, $p < 0.001$). This indicates that the null hypothesis is rejected, and an alternate hypothesis is confirmed.

The means for the automation malfunction scenario ($\bar{x} = 42.49$) were higher than those for the normal operation scenario ($\bar{x} = 37.35$) (see Figure 7), suggesting that team coordination was significantly higher during automation malfunction. Additionally, the coefficient of variation for the teamwork requirement of the normal operation scenario $\left[\frac{SD}{\bar{x}} = \left(\frac{19.94}{37.35}\right) * 100 = 53\%\right]$ was slightly higher than that of the automation malfunction scenario $\left[\frac{SD}{\bar{x}} = \left(\frac{21.57}{42.49}\right) * 100 = 51\%\right]$.

Statistical analysis was conducted using the Wilcoxon signed rank test to analyze the relationship between teamwork requirements in cases of automation malfunction and normal operation scenarios. The results showed that there were 13 positive differences, indicating that the total teamwork requirement was higher in the automation malfunction scenario than in the normal operation scenario. There were zero negative differences, indicating that the teamwork requirement was not lower in the automation malfunction scenario. Finally, there were 19 ties, indicating that there were instances where teamwork requirements were the same in both scenarios (see Figure 8).

6 | DISCUSSION

6.1 | Team communication

The results of RQ1 suggest that the dynamics of team communication change during an automation malfunction event in an engine room, considering different elements of the socio-technical system, that is, crew organization, task type, structured procedures, organizational practice, and work environment. An automation malfunction in the engine room combined with a fixed number of overwhelmed crew members constitutes an emergency. Unlike other emergency responses, crew proficiency was found to be one of the crucial factors in successful management of automation-related incidents. Senior-level officers' leadership and management skills also influence their team communication. Gregoriades and Sutcliffe (2008) found a positive correlation between workload and communication between humans and technology, supporting the findings of this study.[62] Moreover, Stanton (2014) examined the link between communication and task engagement in modern submarine operations, showing how the computational (i.e., cognitive or inherent tasks) and representational processes (i.e., task performance or physical actions) of complex systems interact and influence each other.[63]

Occasionally, engineers may be reluctant to follow procedures during emergencies, and a lack of standard procedures or checklists has been reported. Consequently, a lack of procedures may affect human communication in an engine room, as revealed during the qualitative interviews in this study. Lundh et al. (2011) found that engineers do not always follow standard procedures even when they are

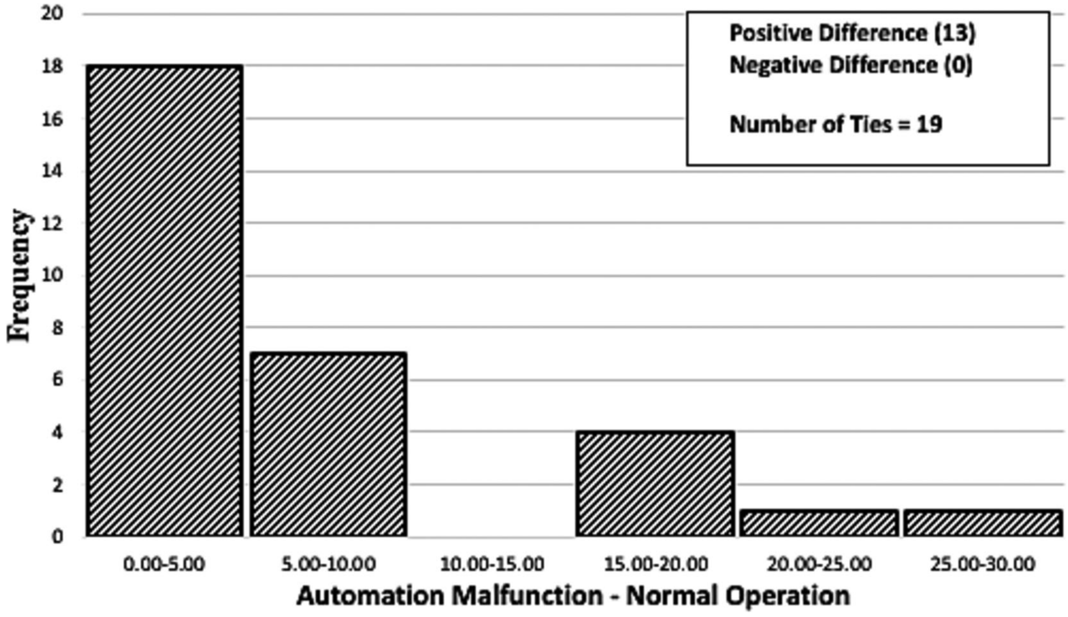

FIGURE 8 Graph representation of the ranks of Wilcoxon signed ranks test (Generated from SPSS, Version 26).

available. Russ et al. (2013) demonstrated that following checklists can reduce visible errors and improve teamwork and communication, whereas poorly structured procedures can have the opposite effect.[64] Winograd et al. (1986) suggested that standard practices shape communication in engine rooms, and any alteration to those practices would affect communication.[65]

The multifaceted impact of automation malfunction on team communication (i.e., "individual–group" interaction) in a complex environment can be delineated through Koester's (2007) Septigon model. Grech et al. (2008) discuss different navigation, drill, and operation scenarios in ships where the dimension of coordination varies among the seven domains of the Septigon model.[66] For example, when one person navigates from the bridge, "individual–technology–practice" from the available seven nodes of socio-technical system interact resembling "person–joystick–experience". On the other hand, the interaction extends to a "group" level if there is more than one person engaged in navigation forming "individual–group–technology–practice" linkage in the Septigon model (see Figure 9).

Similarly, in engine room operations, the team communication during the normal automated environment can be attributed to the interactions among "EOOW–the Chief or Second engineer–Engine rating" (i.e., individual–group level interaction in the Septigon model). During an automation malfunction event, team communication is affected by several other dimensions such as altered communication techniques, crew stress, and the absence of structured procedures. For example, voice communication was found to have a significant positive impact on human performance in team.[67] The increase in verbal communication in the engine room environment could also be attributed to the crew's efforts to maintain performance levels before and after an automation malfunction event. Here, the noisy physical environment of the engine room, stress, and panic can significantly affect verbal communication among individuals. The study also suggests that crew behavior and norms (represented by both "practice" and "society and culture" node in Septigon model) are affected by company standards depicted through checklists, highlighting the effect of organizational environment on team communication.

The effect of automation malfunction on team communication reveals a clearer account through a comparison between normal operation and malfunction scenarios and their associated socio-technical interactions in the Septigon model (see Figure 10).

6.2 | Team coordination

RQ2 aimed to investigate the impact of automation malfunctions on overall team coordination within an engine room environment. To accomplish this, the study measured "total teamwork required" from CDA, summarizing statistics for both normal and malfunction scenarios and grouping them as dependent variables for analysis. The Wilcoxon signed rank test was employed for hypothesis testing, resulting in the null hypothesis being rejected.

According to the findings, there is a significant increase in coordination demand during automation malfunction scenarios compared with normal operation, thus confirming the primary hypothesis. Previous research by Guastello et al. (2018) examined the relationship between the position of responsibility and coordination demand, suggesting that individuals in leadership roles tend to perceive coordination demand as lower than others do.[68] A possible explanation is that experienced personnel, such as management-level engineers, possess a more comprehensive understanding of the skills required to address emergencies and consequently perceive a lower workload and coordination demand. Guastello et al. (2018) also posited that experienced workers might perceive an increase in coordination demand as they can identify certain requirements that others cannot.

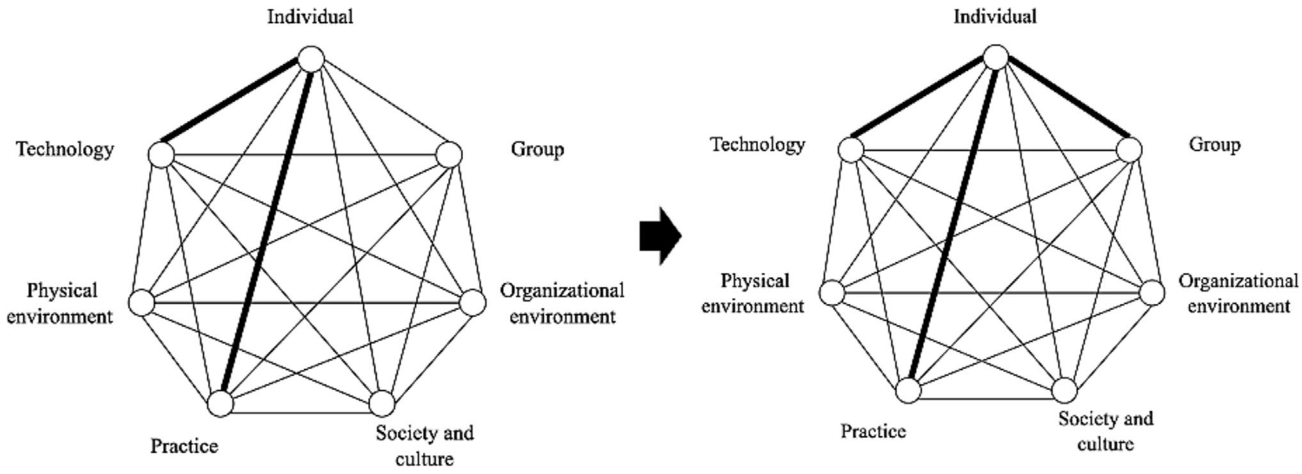

FIGURE 9 Varying socio-technical interactions (adapted from Grech et al., 2008).

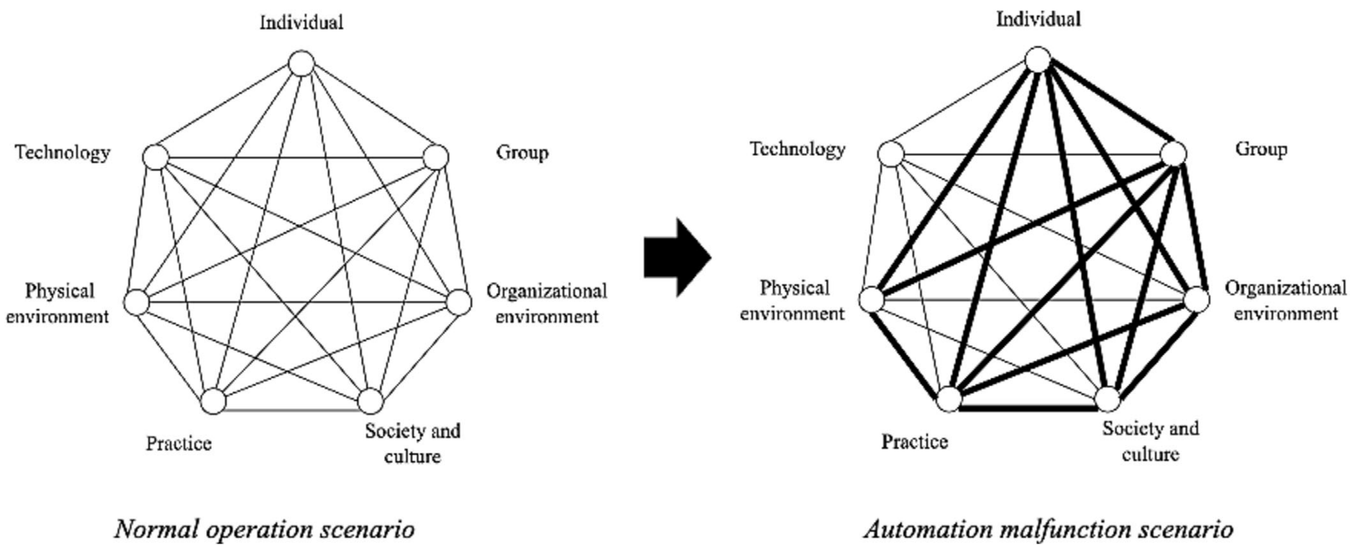

FIGURE 10 Comparison of normal operation and the malfunction scenario in a socio-technical system.

Another research stream investigated the differences in coordination demand among various groups of workers, attributing this phenomenon to the presence of multiple mental models within a team.[69,70] Given that the survey participants in this study included both management-level and operational-level engineers, it is important to not undermine the possibility that an increase in coordination demand could be attributed to multiple mental models within the group of participants. Moreover, no categorical analysis was done based on the respondents' level of competence in this study.

Future research on training needs analysis based on the competence level of seafarers for automation malfunction events may enable marine engineering teams to develop more effective strategies for enhancing communication and managing higher coordination demands during such situations. Further workload analysis of specific malfunction scenarios might provide additional insights into how human agents can better adapt to teamwork environments, especially during time-sensitive situations, such as ship maneuvering. This could also help to identify potential gaps in existing equipment and team configurations on merchant ships, ultimately contributing to more efficient team communication by addressing these issues.

7 | CONCLUSIONS

The continuous integration of advanced automation systems in ships has significantly influenced various aspects of maritime work environments. This study examines the impact of automation malfunction on team communication and coordination in a ship's engine room using both qualitative and quantitative methods.

Qualitative analyses indicated that automation malfunctions disrupt the work environment through heightened unplanned human–human and human–machine interactions within the socio-technical system. This study identified the specific nodes of an engine room socio-technical system that are affected by heightened coordination demand. For example, previously passive elements of the socio-technical system, such as physical and organizational aspects, assume more active moderating roles, creating imbalances in team dynamics. Quantitative evaluations further showed an augmentation in team coordination due to automation malfunctions, thus endorsing the qualitative findings.

The results of this study can guide system designers and marine engineers in optimizing team performance in automated, safety-critical work environments. Incorporating scenario-based simulations during training can prepare engineers for unforeseen automation malfunctions in the engine rooms. Moreover, the identified gaps in non-technical skills such as communication and leadership can be addressed through targeted adaptive training. Future studies could explore the underlying theoretical aspects that dictate efficient team communication and coordination in maritime operations.

AUTHOR CONTRIBUTIONS

Hasan Mahbub Tusher: Conceptualization (lead); data curation (lead); formal analysis (lead); methodology (lead); software (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Salman Nazir:** Funding acquisition (lead); methodology (supporting); project administration (lead); supervision (equal); validation (equal); writing – original draft (supporting); writing – review and editing (supporting). **Steven Mallam:** Conceptualization (supporting); formal analysis (supporting); funding acquisition (supporting); methodology (supporting); project administration (supporting); supervision (equal); validation (equal); writing – original draft (supporting); writing – review and editing (supporting). **Zaili Yang:** Project administration (supporting); validation (equal); writing – original draft (supporting); writing – review and editing (supporting). **Umer Asgher:** Project administration (supporting); validation (equal); writing – original draft (supporting); writing – review and editing (supporting). **Risza Rusli:** Project administration (supporting); validation (equal); writing – original draft (supporting); writing – review and editing (supporting).

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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