Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen

doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P3513-cd

Challenges and opportunities in remote operations of automated passenger ferries identified using the CRIOP method

Jooyoung Park

Department of Design, Norwegian University of Science and Technology, Norway. Jooyoung.Park@ntnu.no

Stig Ole Johnsen

SiPå, SINTEF Digital, Norway. Stig.O.Johnsen@sintef.no

Mina Saghafian

The Institute of Transport Economics (TØI), Norway. Mina.Saghafian@toi.no
Department of Design, Norwegian University of Science and Technology, Norway.

Ole Andreas Alsos

Department of Design, Norwegian University of Science and Technology, Norway. oleanda@ntnu.no

The launch of MF Estelle, the world's first commercial autonomous passenger ferry, in Stockholm in 2023 has accelerated the need to establish a Remote Operation Centre (ROC) to manage multiple vessels with fewer human supervisors, reducing operational costs. This transition, by technological development and practical insights from MF Estelle's operations, presents significant challenges - particularly in ensuring safety when replacing onboard human operators with remote systems. To address these challenges, the CRIOP method (Crisis Intervention and Operability Analysis) was applied for the first time to a ROC for autonomous ships, emphasizing Human Factors and a Human-Centred Design approach. This paper outlines MF Estelle's current operations, explores potential ROC concepts and development phases, and presents the CRIOP workshop activities. During the workshop, MF Estelle's operator shared his challenges and concerns regarding the ROC. Additionally, the checklist and scenario analysis identified key issues, including (1) conducting task analysis to support safer and more human-cantered ROC design and ferry operations, (2) ensuring situational awareness (SA) for ROC operators using tools like alarms and CCTV, (3) designing effective communication between ROC, passengers, and VTS/emergency centres, and (4) mitigating critical scenarios such as fires on the ferry, fires in the ROC, and high-traffic collisions through robust design, training, and organizational measures. Finally, the paper proposes recommendations for human factor engineering and design to mitigate these challenges and support the safe and reliable operation of autonomous ferries. Key human factors questions addressed include: (1) Who will the remote operators be, and what will their responsibilities entail? (2) How will passengers be managed when the vessel is unmanned? (3) How will ROC operations handle emergencies or dangerous situations?

Keywords: CRIOP workshop, Safety, Human Factors, Meaningful Human Control, Autonomous Urban Passenger Ferry, Remote Operation Centre.

1. Introduction

Autonomous urban passenger ferries are being developed with the expectation of becoming a reliable mode of transport that utilizes urban waterways efficiently. By introducing the Remote Operation Centre (ROC) (Man et al., 2015), ferries aim to minimize human involvement in operations by sharing and teaming tasks with autonomous systems (NAS, 2021, pp. 14-16). These advanced technologies are expected to reduce operational costs, enable the efficient management of multiple ferries from a single ROC (Namireddy et al., 2019), and achieve safety and reliability levels at least similar to conventional ships (Porathe et al., 2018).

A recent demonstration of MF Estelle's remote operation marked a key milestone in advancing autonomous ferry technology (Inspenet, 2024). Zeabuz, a company specializing in maritime autonomous solutions, has been instrumental in advancing this field, leveraging novel technologies to bring the vision of autonomous ferries closer to reality. However, while technological progress continues, the importance of a human-centered approach is often missing (Calvert et al., 2023).

The MAS project - Meaningful Human Control of Digitalization in Safety-Critical Systems (Johnsen, 2022) - aims to update and improve the CRIOP method by: (i) focusing on safety, meaningful human control, and human involvement to support increasing digitalization in the industry, specifically in remote operations and autonomous systems across sectors such as oil and gas, autonomous vessels, and other transportation systems (Johnsen et al, 2020); and (ii) applying these improvements to relevant use cases in the design and operation of safety-critical control centres/rooms. To support the update, a CRIOP workshop was conducted to ensure that MF Estelle's ROC development follows best practices throughout the design phases as outlined in standards such as ISO 11064: Optimising the ergonomics of control rooms and ISO 9241-210: Human-centred design for interactive systems.

Including human factors from the start is critical for supporting safety, efficiency, and usability (Johnsen et al., 2011). The cost of changes increases exponentially from early concepts to design, build, and operation. Therefore, conducting a CRIOP workshop at an early stage was both appropriate and beneficial.

This paper presents the results of the CRIOP workshop for the design and development of ROC. It proposes essential future research to address the identified challenges and enhance meaningful human control and safety.

1.1. *MF Estelle*

The MF Estelle, as illustrated in Figure 1, is the world's first commercial autonomous urban passenger ferry and began service on June 8, 2023 (Kosmajac, 2024). As of August 2024, it has accommodated over 30,000 passengers, with up to 400 passengers daily. The ferry operates across Riddarfjärden in central Stockholm, covering the 800-meter crossing between Kungsholmen and Södermalm in about 6 minutes with a cruising speed of 4.5 knots. The ferry can accommodate 24 passengers and one operator. The operator, Torghatten, aims to expand the service to new routes in nearby areas and efficiently manage multiple ferries through a safe and reliable ROC.

Fig. 1. MF Estelle (source: Brødrene Aa)

The ferry's development was based on research from the "milliAmpere" ferries (Eide et al, 2025; Brekke et al., 2022) by the Norwegian University of Science and Technology (NTNU). The "milliAmpere2" is claimed to be the world's first autonomous ferry in trial operation open to the public (Alsos et al, 2024).

MF Estelle is equipped with two operational modes: a dynamic positioning (DP) system for direct maneuvering and an autonomy system in which the onboard captain presses a "start crossing" button, allowing the vessel to follow a predefined nominal path. The captain can switch between these two modes as needed. Additionally, the captain can engage autonomy in speed override mode, where the autonomy system maintains the vessel on the nominal path while the operator adjusts the speed using a lever.

1.2. *ROC demonstration*

In August 2024, Zeabuz demonstrated the remote operation of the MF Estelle in Stockholm. The demonstration was conducted without passengers but with an onboard operator on standby while the vessel was remotely controlled from an ROC mock-up in Trondheim. The ROC was integrated with the ferry's existing control systems and enhanced with CCTV and autonomy cameras, providing the remote operator with comprehensive oversight and precise control capabilities, as illustrated in Figure 2. The vessel successfully navigated a crossing along a predefined route, maintaining safety through real-time obstacle detection. Additionally, the demonstration featured a manual speed override test during the crossing, which was smoothly executed by a remote operator from Trondheim (Inspenet, 2024).

While this demonstration marked a crucial first step in validating the feasibility of autonomous operations, it is still premature to conclude that fully remote operations are viable. Although the technology is nearing maturity, maintaining stable network connectivity remains a critical challenge. Ensuring safe operations with passengers and without an onboard operator, along with ergonomic and optimized control center designs for overseeing multiple vessels, are key priorities for future development.

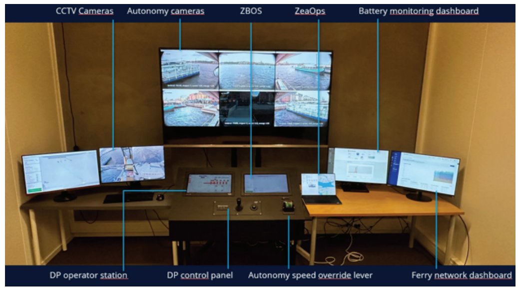

Fig. 2. Early-stage setup of the ROC (source: Zeabuz)

In addition, passenger acceptance plays a crucial role in the successful remote operation of autonomous ferries. Studies indicate that trust in autonomous systems is shaped by perceived safety, familiarity with technology, and the assurance of human oversight (Calvert et al., 2023). During the public trial operations of milliAmpere2 in 2022 and 2024, research on passenger experience, attitude towards autonomous ferry, and feedback were investigated (Eide et al., 2025; Veitch et al., 2025; Veitch et al., 2024). For MF Estelle's reliable remote operation, maintaining human connection through communication tools, such as PA systems and video calls, is vital for passenger reassurance. Current research continues to explore these dynamics to develop effective strategies for enhancing passenger trust and acceptance.

1.3. *Human-AI teaming in autonomous operations*

Adopting autonomous systems and AI in operations presents potential opportunities to enhance oversight capacity (NAS, 2022). These include reducing workload by delegating repetitive and monotonous tasks to autonomous systems, enabling remote operations, and improving efficiency to potentially allow the simultaneous oversight of multiple vessels. However, there are also risks, as both AI and human operators have inherent limitations that can lead to unintended operations or incidents.

AI performs effectively only when it has been properly trained or programmed but struggles in new, unfamiliar environments (Woods, 2016). Its performance may be compromised in noisy or unpredictable settings due to perceptual limitations (Yadav et al, 2021), and it lacks a causal understanding—relying solely on pattern recognition rather than reasoning (Pearl & Mackenzie, 2018). Additionally, if the training data is biased, the AI's decisions are likely to reflect those biases (Ferrer et al., 2021).

Human performance can also be influenced by both AI performance and the operator's capabilities (NAS, 2022). When AI decisions are consistently robust and reliable, operators may develop over-reliance, leading to complacency and reduced vigilance (Parasuraman et al., 1993). This can result in the misconception that the AI system is fully autonomous and flawless (Bradshaw et al, 2013). In rare but critical situations requiring timely human intervention, operators may be out of the loop, causing delays in regaining situational awareness (SA) and hindering effective responses (Moray, 1986). Furthermore, even short-term reliance on AI can lead to rapid deskilling, degrading the operator's manual competencies (Casner et al., 2014). Misunderstanding how the AI system functions can further result in inappropriate interactions, compromising overall system performance (Endsley, 2019).

Thus, systems should be designed with a clear understanding of the human operator's limitations, and operators should be thoroughly trained to comprehend the system's functions and constraints (European Union, 2026).

1.4. *Meaningful human control*

Autonomous systems with self-learning capabilities can make decisions independently, but this feature introduces challenges. These systems often behave in ways that are complex, unpredictable, and opaque, making it difficult for human operators to understand their decisions or intervene effectively (NAS 2022; Mittelstadt et al., 2016). In critical situations, this unpredictability may prevent operators from responding appropriately or in a timely manner.

Building on this, ensuring not just control but Meaningful Human Control (MHC) is essential in autonomous operation systems, as they increasingly rely on the interaction between humans and technology. Automation must function in ways that align with human expectations and understandings (Calvert et al., 2019).

In this paper, we define MHC in the context of remote operation as the ability of human operators and systems to work together in a way that ensures safe and reliable operations. Specifically, MHC requires necessary information to support comprehension of the SA and the ability to control the future state of the system within the limits of the human operator, the technology, and the organization.

Thus, our view on MHC is a result of systematic Human Factors (HF) based design, integrating best practices in usability and SA; realistic operational conditions, including training and workload; and ensuring that the system, organization, and human operators have the capacity to learn, change, and adapt by addressing the root causes of accidents or incidents (Johnsen & Park, 2025).

1.5. *IMO's stance on autonomous ship operations*

The International Maritime Organization (IMO) is actively developing a regulatory framework for Maritime Autonomous Surface Ships (MASS) to address safety, operational, and human factor challenges associated with autonomous shipping. The Maritime Safety Committee (MSC) is leading this effort, with a road map aiming to adopt a non-mandatory MASS Code by May 2026 and a mandatory version by 2032 (MSC, 2024). The framework emphasizes the need for meaningful human control, ensuring that remote operators maintain accountability for vessel safety, even in autonomous modes. This aligns with the challenges identified in this paper, particularly the need for robust communication, situational awareness, and emergency response protocols in ROCs.

MSC 107/5/1, MSC discussing various aspects related to MASS operations, including the role and responsibilities of the master of a MASS, as well as the competencies and requirements for the master and crew. Additionally, MSC is considering the implications of expanded MASS operations, including multi-vessel supervision and multiple supervision arrangements for a single voyage.

Regarding the issues discussed in this paper, the MSC (2023) agreed that the person responsible for MASS operations must maintain overall accountability for the vessel, even when it is operating autonomously. If there are crews or other individuals on board, a master must be present to ensure their safety. However, depending on the vessel's technology and operational setup, the master may not need to be physically on board. Regardless of the operational mode or degree of autonomy, the master of a MASS must have the capability to intervene whenever required.

2. Method

To identify challenges and key considerations in MF Estelle's unmanned operation and ROC design, the first-ever CRIOP for an ROC for an autonomous ship was conducted on August 15th and 16th, 2024, with a focus on Human Factors (HF) and a Human-Centred Design (HCD) approach.

2.1. *CRIOP methodology*

CRIOP (Johnsen et al., 2011) is a standardized methodology for Crisis Intervention and Operability analysis, originally developed for the oil and gas industry. Its primary purpose was to evaluate control centres with a focus on human factors and the conditions necessary for effective crisis management. Over time, CRIOP has evolved into a comprehensive approach for verifying and validating the ability of control centres to safely and efficiently manage different operational modes. The scope includes various centres of control where information is presented to support SA and manage operations in a safe and efficient manner, such as drillers' cabins in the oil and gas industry, ship bridges, remote operational centres, and emergency centres in general.

The methodology is highly versatile and can be applied to various safety-critical control centres, such as central control rooms, emergency control rooms, and ROC. CRIOP incorporates three key components: (i) checklists that address critical aspects of control centre design, documenting "work as imagined," (ii) scenario analysis of key situations to explore "work as done," and (iii) a learning arena where operators, designers, and management collaborate to evaluate and optimize control centre performance based on practical experience. This combination ensures that control centres are designed and operated to handle both routine and critical scenarios effectively and safely (Johnsen et al., 2011). The method has been enhanced to address the challenges of increased digitalisation, remote operations, and autonomy, making it ideally suited for analysing autonomous ferries.

2.2. *Preparation*

The preparation of the CRIOP workshop followed these four steps:

(i) Recruiting: Stakeholders from management (Torghatten), developers (Zeabuz), facilitators (NTNU, SINTEF), risk assessors (Zeabuz), and MF Estelle operators (Torghatten/Zeam) were recruited. A hybrid format (with personal participation and remote participation) was adopted due to participants from locations in Trondheim, Oslo, and Stockholm.

(ii) Scheduling: A 2-day workshop was deemed sufficient, compared to the typical 5-day format in the oil and gas industry, due to the early design stage and simpler operational concept (see 1.1.).

(iii) Documentation/Information Gathering: Materials such as hazard analyses, equipment descriptions, a mock-up layout, and operator feedback on the ROC were collected, though full documentation was limited at this stage.

(iv) Checklist Creation: Relevant questions were selected from an extensive checklist and tailored for the ROC's design phase, covering eight areas: initial issues, remote operation, control and safety systems, job organization, procedures, working environment, layout, and training.

2.3. *Workshop activities*

To get a common understanding, compare to best practices, and discuss work as done, the following activities were conducted:

(i) Presentation: The workshop began with two presentations. In the first, an experienced MF Estelle operator shared his routine for manoeuvring the ferry, explained his team's operations, outlined challenges and concerns regarding the transition to unmanned operation and moving to an ROC, and identified relevant scenarios of interest based on operational experience. In the second presentation, the HF expert introduced the CRIOP methodology, a risk-based approach that qualitatively models and describes risks while integrating HF issues into the design using best practices.

(ii) General Analysis (checklist): This phase involved using checklists to ensure that the current MF Estelle operation and ROC design meets specified requirements based on best industry practices. It helped familiarize the participants with the ROC concept under review, which should be completed before proceeding to the more detailed Scenario Analysis.

(iii) Scenario Analysis: Three key scenarios were selected and discussed with participants to examine potential future incidents. This analysis aimed to identify issues that needed to be addressed and explore ways to mitigate them through further design and development of the ROC. Although the STEP method (Hendrick & Benner, 1987) is typically applied in this phase, a simplified version was used due to hybrid participation, relying on text and descriptions to list the actors and sequence of actions. A formal STEP diagram was created at a later stage, documenting the actors and activities in the standard format.

(iv) Wrap-up and finalizing: After completing the analyses, the facilitator officially concluded the workshop. Before the termination, participants briefly shared their perspectives and future goals. Shortly after the workshop, a result report was prepared by the organizers to document findings and outcomes, which was then shared with the participants.

3. Results

The CRIOP workshop revealed a number of challenges and concerns from three different perspectives.

3.1. *Challenges and concerns identified regarding ROC*

During the workshop, the operator shared several challenges and concerns related to the design and operation of the ROC. These insights were essential in aligning participants and focusing discussions. The identified issues can be categorized into three main areas: situational awareness (SA), technical competence, and operational safety.

3.1.1. *Situational awareness and navigation support*

Maintaining SA in the ROC is vital for safe and efficient operations. Tools such as bird's-eye-view map interfaces, 360-degree overhead displays, and filtered area charts can help operators maintain a clear understanding of the vessel's surroundings without being overwhelmed. Fault detection and system diagnostics are also critical, as identifying and addressing issues remotely can be challenging. Systems must continuously adapt and improve to enhance fault detection capabilities and ensure reliable operation. Additionally, during docking procedures, operators in current operations visually confirm the vessel's mooring to the dock. However, for fully unmanned operations, autonomous systems must be developed to ensure safe and secure mooring without manual intervention.

3.1.2. *Technical competence and system usability*

The maritime industry's shift toward digitalization presents significant challenges, particularly regarding the technical skills required to operate advanced systems. Many captains lack familiarity with digital controls and basic computer tasks, making training and user-friendly system design critical. The ROC and onboard systems must lower the skill threshold with intuitive interfaces and extensive training to ensure operators can effectively manage the systems.

3.1.3. *Operational safety, human factors, and passenger handling*

Operational safety emerged as a key concern, encompassing alarm management, passenger handling, and operator workload. Alarm systems must prioritize essential notifications while minimizing non-vital information to prevent operator overload.

Passenger handling is especially complex, as passengers represent the most unpredictable and high-stakes "cargo" on board. The operator emphasized the importance of maintaining a human connection between passengers and the ROC, particularly during emergencies. Tools such as public address (PA) systems, visual alerts, and two-way video calls are essential for communication, ensuring passengers feel reassured and connected. Additional features, like indicators signalling when the ROC operator is actively monitoring the vessel, could enhance passenger trust and safety. The operator also suggested that an onboard safety manager might be necessary for managing passenger behaviour in the near term.

Managing operator workload is also critical for operational safety. Strategies such as limiting work hours, providing regular breaks, and optimizing environmental factors (e.g., sound, lighting, and air quality) can help reduce stress and maintain focus during operations.

By mitigating these challenges, the ROC design can better meet the needs of operators, ensuring safety, usability, and efficiency in autonomous ferry operations.

3.2. *CRIOP checklist analysis*

The CRIOP checklist analysis highlighted key areas for ensuring the ROC's effective design and operation. The focus was more on addressing and guiding future work with HF involvement and an HCD approach rather than verifying and validating the current design, as the ROC development is still in its early stages. These results can be grouped into three main categories: ROC design and usability, SA and system reliability, and communication and operational safety.

3.2.1. *ROC design and usability*

The design of the ROC should align with functional and task analyses, integrating user involvement to ensure usability and efficiency. This includes addressing operational tasks such as administrative duties and collaboration with remote installations. Concept analysis is necessary, including potential redesigns for MF Estelle, and development work should adhere to industry standards like ISO 11064 and ISO 9241-210. Ergonomic room layouts and workplace designs should support operator posture, while optimal working environments must be maintained with proper lighting, temperature control, air quality, and noise reduction. Robust, error-tolerant systems are essential, particularly for critical operations like docking and undocking.

3.2.2. *Situational awareness and system reliability*

Maintaining SA is critical for safe and efficient operations. High-performance HMI systems should be designed following standards like IEC 63303 and informed by task analyses and user needs. These interfaces must allow operators to take control easily, support rapid information detection with consistent symbols and icons (OICL, 2024), and handle errors gracefully with fault-tolerant features. Cognitive workload assessments are necessary to ensure mental capacity is effectively managed, and AI systems must provide transparency in in-the-loop and out-of-the-loop operations. Enhancements such as sound cues, motion-feedback chairs, and bird's-eye-view displays can improve navigation and SA. Alarm systems, based on standards like EEMUA 191, should minimize false alarms, prioritize essential notifications, and provide clear, actionable information to operators. Reliable CCTV systems, adhering to standards like IEC 62672, should support effective monitoring and visual oversight of ROC operations. Systematic testing is also vital for ensuring reliability. User testing under realistic scenarios, including equipment and response time evaluations, should inform refinements to eliminate potential error traps and improve overall functionality.

3.2.3. *Communication and operational safety*

Effective communication and collaboration are central to ROC operations. Clearly defined roles and responsibilities, based on task analyses, are necessary to ensure seamless interfaces between vessels, passengers, and emergency response teams (Park et al., 2025). Communication systems, such as PA systems, alerts, and video calls, must provide a reassuring human connection for passengers, especially during emergencies. Risks, whether human, organizational, or technical, should be identified, prioritized, and mitigated systematically.

Passenger handling is another critical area, requiring the design of safe and secure protocols for ferries, docks, and ROCs. Safety measures, such as communication systems and CCTV, must focus on managing passenger behavior effectively while ensuring consistent human interaction to build trust and safety. Procedures must be developed systematically, guided by functional and task analyses, to support fault-tolerant practices. Training programs should enhance operator competence through scenario-based exercises and simulators, ensuring systems are intuitive and user-friendly. Support systems for the ROC captain during abnormal situations should be readily available to maintain operational safety.

3.3. *Emergency scenario analysis*

Three key emergency scenarios were identified based on the shared understanding of MF Estelle's operation mode, the state of the ROC mock-up, and the CRIOP checklist analysis. Given the vessel's straightforward and short operation mode, compact size, and urban location, the range of potential scenarios is relatively narrower compared to those identified in similar projects (Thieme et al., 2023).

While Figure 3 focuses on fire-related scenarios, other critical incidents, such as grounding and collisions, were also analysed during the workshop. These scenarios highlighted the necessity for robust emergency protocols, including real-time hazard detection, effective communication systems, and coordinated response plans.

The scenarios discussed include: (i) Fire onboard the ferry: Addressing evacuation procedures on the water with support from the ROC, (ii) Fire in the ROC or loss of communication with the ROC: Exploring contingency plans to maintain operations and passenger safety, and (iii) Collision with another rogue vessel or grounding: Both collisions and grounding pose significant risks to small passenger ferries operating in coastal waters, where shallow depths and navigational errors can lead to accidents. Effective mitigation strategies include real-time depth monitoring, advanced charting systems, and AI-driven navigation algorithms that dynamically adjust routes to avoid hazards. In the event of a collision or grounding, protocols must ensure a rapid response and passenger safety, including coordination with local emergency services and the utilisation of onboard systems to stabilise the vessel.

The identified scenarios were reviewed using STEP analysis to identify proactive barriers aimed at reducing the likelihood of these events and mitigating their consequences should an accident occur. This approach ensures that safety measures can be effectively designed and integrated during the development phase, as illustrated with one example in Figure 3.

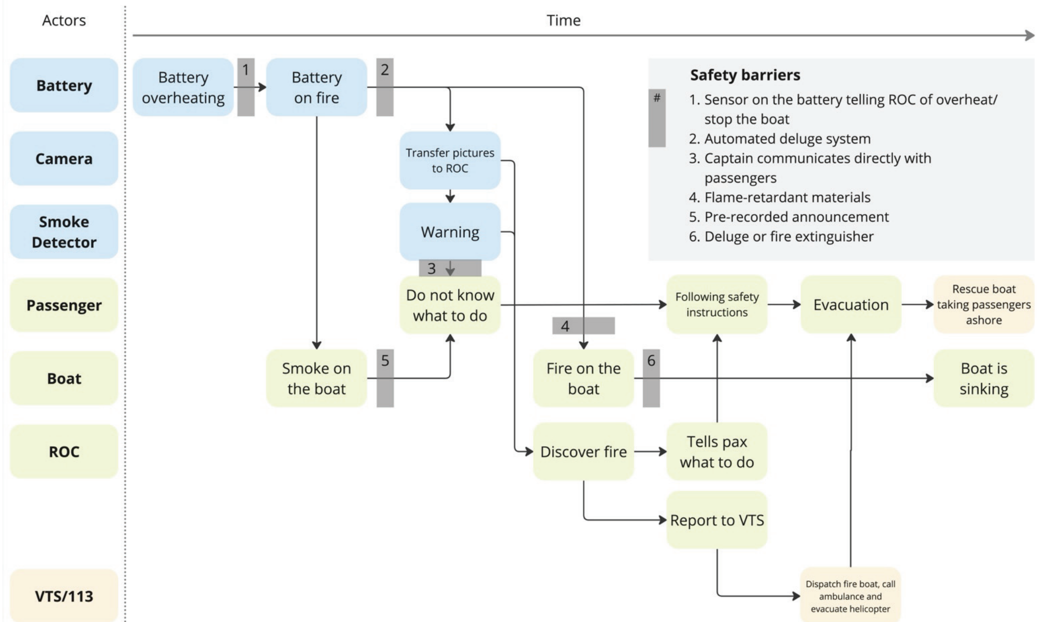

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Fig. 3. STEP analysis combining with safety barriers for *Scenario 1: Fire onboard the ferry*

4. Discussion and future work

The CRIOP workshop provided insights into the challenges and opportunities of designing an ROC for autonomous ferries. The findings emphasize the critical importance of adopting the HCD approach, particularly in enhancing SA, usability, and operational safety to achieve MHC. For instance, the need for high-performance HMI systems is evident, as they must support the ROC captain's decision-making process while ensuring passenger safety through effective communication tools.

Although this study focuses on small passenger ferries like MF Estelle, the findings have broader implications for larger vessels. The principles of HCD and the CRIOP methodology can be adapted to address the increased complexity of larger ships, such as cargo vessels and cruise ships. Key considerations for scalability include: (1) the need for more advanced navigation systems to manage longer voyages and congested waterways, (2) the integration of multi-vessel supervision capabilities in Remote Operation Centers (ROCs), and (3) the development of robust communication protocols to support larger crews and diverse operational scenarios. Future research should explore these adaptations to enhance the safety and efficiency of autonomous systems across the maritime industry.

While MF Estelle is equipped with advanced navigation and monitoring systems - including object proximity visual alarms, autonomy health status updates, battery alerts, and fire alarms - the presence of specific danger alert systems, such as collision avoidance alarms, grounding warnings, and alarms for man overboard, remains an area for further investigation.

However, the study has some limitations. Conducted during the early design phase of the ROC, the workshop's recommendations may require refinement as the development progresses. Additionally, while the scenarios addressed significant events, their scope was limited and somewhat superficial. Further testing in real-world settings is necessary to validate and refine these findings.

One of the primary objectives of developing the ROC is to reduce operational costs. However, the findings suggest that more robust autonomous systems are required to effectively support operators' SA, along with potential redesign and reconstruction of ferry and port infrastructure. Furthermore, to oversee multiple vessels simultaneously, the current design might necessitate maintaining the same number of control stations in the ROC due to potential delays when transitioning control from one vessel to another. This issue warrants thorough review and consideration in future development phases.

These limitations present opportunities for future research and development. Iterative testing of ROC prototypes, incorporating real-world trial operations, and expanding the scope of scenario analysis is essential for improving system safety and reliability. Additionally, addressing broader industry challenges, such as digitalization and operator training, will be crucial to ensuring the long-term success of autonomous ferry systems.

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ISBN: 981-973-0000-00-0 :: doi: 10.3850/981-973-0000-00-0 esrel2022-paper

5. Conclusion

This CRIOP workshop has provided valuable insights into designing and developing a safe and efficient ROC for managing autonomous ferries. By addressing key HF considerations, the findings emphasize the importance of designing systems that prioritize safety, usability, and operational reliability to support MHC. A task analysis-based design, effective SA tools, robust communication systems, and comprehensive emergency management strategies are critical to achieving these goals.

The workshop also addressed the following key HF questions:

(i) Who will the remote operators be, and what will their responsibilities entail?
Remote operators are expected to have a combination of maritime expertise and technical competence. Their primary responsibilities will include monitoring vessel operations, responding to alarms, managing emergencies, and ensuring passenger safety. Training programs and user-friendly interfaces are essential to enable operators to perform these tasks effectively.

(ii) How will passengers be managed when the vessel is unmanned?
Passenger management will rely on robust communication systems, such as PA systems, visual indicators, and two-way video call capabilities. These systems will ensure passengers feel connected to a human presence at the ROC, providing instructions and reassurance during normal operations and emergencies. Additionally, adjustments or redesigns of vessel and port infrastructure may be necessary to guide passenger behavior, enhance safety protocols, and support efficient boarding and evacuation procedures. Applying the hierarchy of controls (NIOSH, 2024) can help mitigate risks by focusing on hazard elimination through design changes, scope redefinition, or system reorganization. These measures will ensure passenger safety and confidence in the unmanned ferry operations.

(iii) How will ROC operations handle emergencies or dangerous situations?
Emergency scenarios, such as fires, collisions, or communication losses, will be managed through predefined protocols supported by advanced alarm systems, SA tools, and coordinated communication with VTS and local emergency services. Continuous training and scenario-based testing will ensure operators are prepared to handle such events effectively.

Finally, the findings emphasize the importance of initiating the development of the ROC prototype using agile methodologies, incorporating real-world trials to gather operational data and refine the system iteratively. These efforts will lay the foundation for safer and more reliable autonomous ferry operations in the future.

Acknowledgement
The authors express their gratitude to the participants of the CRIOP workshop. This work was supported by the MAS project, RCN: 326676.

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