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Safety on automated passenger ships: Exploration of evacuation scenarios for coastal vessels

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ABSTRACT

Many advancements are being made within the domain of autonomous shipping, motivating discussions of corresponding amendments to international safety regulations within the International Maritime Organization. Near-coastal passenger ferries are a form of sea traffic that has been the target of automation trials due to their short voyages and relatively protected waters of operation. This study investigated emergency evacuation from a range of such ships, covering both the current situation (focused on crew tasks, external rescue actors and interactions) and safety aspects that should be considered when automation brings about new work patterns, such as remote supervision and control. The study employed qualitative methods – interviews, field visits and a stakeholder workshop. Results give insight into ferry evacuation processes and challenges in their current form. In addition, results from the application of different automated evacuation scenarios suggest that more detailed studies are needed within the areas of remote operation situation awareness, remote operator and onboard personnel competencies, passenger safety information and communication, simple and robust evacuation equipment, technical means allowing assistance between autonomous and regular ships, and lastly, both procedures and interfaces for collaboration in a changing rescue network.

1. Introduction

Today, intensive research is underway on automation and land-based control of ships, with driving forces such as environmental benefits, increased flexibility, frequency in operations (Goerlandt and Pulsifer, 2022) cost savings (Kim et al., 2022) and increased safety (Reddy et al., 2019). But when the new technology is transferred to passenger traffic, new challenges may also arise. One example of such a challenge is emergency situations where a ship must be abandoned by its passengers. The topic of this paper is emergency evacuation from near-coastal passenger ferries and how evacuation practices may be affected by crew reductions, something that is often a consequence (and sometimes the aim) of introducing ship automation and autonomous ships.

A large portion of the world's population inhabits coastal areas, where urban ferries are an integral part of the local transportation system (Reddy et al., 2019). In some respects, ships in coastal traffic have more benign operational conditions than seagoing vessels, with shorter routes over relatively protected waters, and the crew is commonly quite small. These are conditions that make near-coastal passenger ferries an attractive testing ground for automation and land-based control. On the other hand, going from a small crew to no onboard crew is a major change for the industry. Automation and crew reductions must be based on a good understanding of existing evacuation systems and the functions that crewmembers fulfill.

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Current regulations impose several barriers for traffic with unmanned passenger ships, both with regard to international regulations and to regulations applying to the European Union (EU) (Danish Maritime Authority, 2017). Similar findings have been made in relation to national regulations. For example, the Swedish Transport Agency (2019) reports that 'master' is mentioned over 100 times in the Swedish maritime law (Svensk Sjölag) and that changing the master's role and responsibility would require comprehensive work. It is yet unknown how regulations will evolve as the research and development of autonomous shipping continues, but a working group is assigned within the International Maritime Organization (IMO) to address issues related to Maritime Autonomous Surface Ships (MASS) (International Maritime Organization, 2022). In 2019, The Maritime Safety Committee approved interim guidelines for MASS trials (International Maritime Organization, 2019), followed by the EU in 2020 (European Union, 2020). A non-mandatory MASS Code is aimed by IMO to take effect in 2025, followed by a mandatory code in 2028 (International Maritime Organization, 2022).

1.1. *Theoretical background*

Over the past decades there has been increasing interest in the automation of transport systems. New autonomous cargo ships and passenger ferries are now being tested, demonstrated, and put into service in various parts of the world, e.g. milliAmpere in Norway (Brekke et al., 2022; Haugan, 2022), MF Estelle (developed by Zeabuz) in Stockholm (Zeam, 2023), Roboat in Amsterdam (Roboat, 2022) and Falco in Finland (Finferries, 2018). While certain aspects of safety are being thoroughly researched, such as safe autonomous navigation and collision avoidance (Madsen et al., 2022; van de Merwe et al., 2024; Wang et al., 2022; Zhou et al., 2022), research that directly addresses evacuation of autonomous passenger ships is limited, something that also holds true for the general field of autonomous vehicle evacuation. Autonomous systems are already in operation in transport modes other than maritime traffic, such as automatic pilot systems in aviation and autonomous solutions for car, truck, and bus transport. Although several aspects of safety for such autonomous transport modes have been thoroughly researched, little published research is available relating to emergency evacuation. The theoretical background is therefore grounded in previous research on evacuation in other contexts (e.g., rail traffic and traditional shipping) together with some examples of autonomous passenger ferry research that briefly addresses evacuation safety.

1.1.1. *Human factors and automation*

In her pioneering work some 40 years ago, Lisanne Bainbridge (1983) suggested a number of issues that might result from more widespread automation, and in particular, from the interaction between humans and automated systems. In essence, the more complex and critical the automated system, the more skill and knowledge is needed by an intervening human operator when the system fails. However, since the automated system was designed to perform tasks more accurately and/or faster than humans, and the humans no longer have direct experience performing these tasks, it may become very challenging for humans to respond to system emergencies effectively. These are issues that have been connected to both a loss of situation awareness, out-of-the-loop phenomena and degradation of manual skills (Johnsen et al., 2022). Strauch (2018) cites numerous automated transport accidents (most of them related to aircraft autopilot systems), in which human-machine interactions exacerbated the situation. In all cases there is a link between the incident and the ironies described by Bainbridge. Strauch concludes that, until Bainbridge's ironies are addressed, *"the need for designers, trainers, managers, and regulators to consider them [the ironies], the problem will not only continue it will likely increase"* (p. 432).

A common way of approaching the prospects and introduction of automation technologies is to apply task allocation principles, where tasks are assigned to either automated systems or human operators based on an assessment of their respective strengths, such as speed, consistency and reasoning (Hollnagel and Woods, 2005). This approach has been criticized for several reasons, partly for its tendency to downplay human strengths in favor of automation benefits, and partly for its failure to acknowledge the dependencies that characterize work activities in sociotechnical systems, i.e. systems where people and technical systems interact to fulfill common goals (Dekker and Woods, 2002). Substituting certain tasks with automation technologies may undermine the execution of other tasks, as well as the operator's understanding of the overall work system, thus undermining the human contribution to safety. As pointed out by Gauthier et al. (2019), any amount of new training will never compensate for poorly designed systems that result from automation endeavors, something that is especially important to consider in safety-critical environments. Introducing control systems that replace human operators or that introduce changes to existing work practices demands a particular focus on human-machine interfaces and resources that allow operators to make decisions in the new operative environment. In addition, new technologies will also be associated with new technical failure patterns, a risk that must be thoroughly considered (Reddy et al., 2019).

Evacuation has been addressed to some extent in domains other than maritime traffic. For example, autonomous rail traffic, more specifically urban metro systems, has been in operation with some level of automation for roughly 30 years. In preparation for the automation of the Helsinki metro trains, Karvonen et al. (2010) investigated the role of train drivers and found potential issues that could also apply to autonomous passenger ships. Through interviewing drivers and making observations, the researchers found that changing to driverless trains could impact passenger safety. Karvonen et al. observed that metro accidents are rare, meaning that if one occurs, the reason is usually very surprising, and therefore it is difficult to develop protocols for handling the situation automatically. A case study on replacing train drivers with automation by Jansson et al. (2023) found that train drivers fulfill several functions in the event of an accident, such as informing traffic control about the current situation, switching on lights in train tunnels, preventing hazards related to damaged catenary lines, sending emergency messages, and putting up warning signs. When examining the trend to introduce further automation in rail transport (trains and metro), Stene (2018) concluded that more research on passenger evacuation is needed, and that humans are key for coping with unexpected events.

1.1.2. Evacuation of manned passenger ships

Several studies have investigated different aspects of evacuation on roll-on roll-off (Ro-Ro) ships and cruise ships (Burgén et al., 2023; Jørgensen and May 2002; Lundh et al., 2010; Nevalainen et al., 2015; Vassalos et al., 2008), but there are few examples of research specifically studying the case of near-coastal traffic.

In terms of social interaction, when designing an evacuation process for a passenger ship it is important to understand that passengers may not always behave uniformly, or as desired by the operator. For example, in a study by Jørgensen and May (2002) on evacuation of passenger ferries, it was shown that families or groups of people travelling together may choose to find each other first, before proceeding to the assembly station. Similar results were reported by Wang et al. (2020) in a survey amongst 1380 passenger ferry travelers. Their results suggested that factors such as age, gender, mobility, and experience of travel at sea may affect behaviors such as reactions to evacuation orders, returning to cabins, helping others and the willingness to follow others. Near-coastal passenger ships are significantly smaller than the ships studied in these previous research efforts, but there might still be reasons for passengers to not move or act according to the evacuation procedure.

In connection to the issue of passenger behaviors and their causes, there is research that emphasizes the influence of shipboard design on evacuation performance. For example, a study conducted by Ahola et al. (2014) concluded that design factors such as openness and good lighting could be used both to instill a sense of safety among passengers and to facilitate movement. An overall theme within this work is the importance of usability in safety measures such as safety information, route guidance and safety equipment, and the importance of accounting for diverse needs among the passengers, something that relates to design for accessibility. Some passengers may not be physically or mentally able to cope with the environmental conditions that sometimes exist during a ship emergency, such as complex ship layouts combined with trim and heel motions; these issues may have an impact on the accuracy of the models used to plan evacuation operations on board a passenger ship (Jørgensen and May 2002; Sarvari et al., 2019). Similar observations have been made in research applying a *Universal Design* perspective to passenger ferry evacuation (Burgén et al., 2023). Universal design has been defined in the UN Convention on the Rights of Persons with Disabilities (United Nations, 2006) as:

> *"[…] the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design."* (p. 4)

The study by Burgén et al. (2023) showed that the design of ship interiors and evacuation equipment does not always account for the needs of all passenger groups. For example, employing audible alarms that may exclude passengers with reduced hearing, and requiring passengers to move between decks using stairs, which places demands on their physical capabilities. Similar perspectives can also be found in the literature on automated ferries. For example, Goerlandt and Pulsifer (2022) and Borgen et al. (2022) both emphasize the need for autonomous ferry safety solutions that offer effective and perceived safety for all passenger groups, disregarding variations such as age, mobility or disabilities, which is something that Borgen et al. (2022) argue is missing in most evacuation equipment on the market.

1.1.3. Automation and safety in marine passenger traffic

Prior investigations have concluded that an autonomous ship should be able to provide *at least* the same level of passenger safety as a manned ship (DNV-GL, 2018; Mehta et al., 2021; Rødseth and Burmeister, 2015). In practice, ensuring the same level of safety on autonomous ships means that new evacuation technologies may have to be provided as the number of crewmembers on board decreases (Danish Maritime Authority, 2017).

Ships operating in domestic waters are mainly affected by national rules, such as rules based on the International Convention for the Safety of Life at Sea (SOLAS) for safety equipment and safety compliance (Thieme et al., 2023). The fact that current regulations are based on the assumption that a ship's crew fulfills many safety functions on board has been found to stand in the way of increased automation, and so far, little guidance is available that demonstrates how regulations can be fulfilled when the crew is reduced (Johnsen et al., 2022).

IMO defines four levels of autonomy for MASS, included in table 1. A ship must not necessarily be one specific autonomy level but can change between the levels during a voyage.

Although automation technologies are capable of carrying out many of the tasks normally performed by crewmembers, in the available literature on autonomous shipping, humans still remain in the ship control loop (Veitch and Alsos, 2022). All of the research reviewed on this topic envisions one or several persons manning a Remote Operations center (ROC), with tasks including ship supervision (Fjørtoft and Rødseth, 2020), liaison with rescue organizations (Thieme et al., 2023), addressing the passengers, assisting personnel on board (where applicable) (Johnsen et al., 2022), and in some cases, controlling the ship remotely (Pobitzer et al., 2022). In a scenario where autonomous shipping becomes more widespread and ROC operators oversee a number of ships simultaneously

Table 1
Levels of autonomy for MASS (International Maritime Organization, 2021).

Level one	Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
Level two	Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
Level three	Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
Level four	Fully autonomous ship: The operating system of the ship can make decisions and determine actions by itself.

(possibly serving both autonomous and semi-automated vessels), their work could become challenging and might also require new skills, such as knowledge in digital technologies and software engineering (Orfanou et al., 2021). In this context, Wahlström et al. (2015), Strauch (2018) and Kari and Steinert (2021) make note of a wide variety of safety challenges that may be caused by the introduction of automation, including lack of situation awareness, the conveyance of too much information, high workload, boredom, fatigue, lack of trust in automation, problems with decision-making, issues with teamwork, errors that occur in connection with the takeover of control, mishaps related to handoffs, skill degradation, human-machine interface issues, communication challenges, a lack of sensory information in remote supervision (e.g. ship motion), and a lack of "ship sense" (i.e. a feeling for the vessel's behavior and orientation).

With regard to shipboard personnel, studies on public perceptions concerning autonomous passenger ships have shown that people often desire personnel to be on the ship, both for safety and for security reasons (Goerlandt and Pulsifer, 2022; Mehta et al., 2021). Whether any personnel are envisioned to be stationed on board appears to depend on operational circumstances, such as the travel distance and proximity to land. Salonen (2018) conducted a study of the subjective response of passengers that had just used a driverless shuttle in Vantaa, Finland. He asked the passengers to assess their perception of traffic safety (fear of accidents), in-vehicle security (fear of crime), and emergency management while using the driverless shuttle in comparison to a human-driven shuttle. Salonen found that traffic safety was viewed as good, but the perception of both the in-vehicle security and emergency management were worse or much worse in the driverless shuttle. He concluded that passengers feel that the presence of a driver is key for their sense of security and emergency management while using the shuttle. Venverloo et al. (2020) used virtual reality (VR), together with skin conductance measurements and a questionnaire upon completion of the VR scenario, to assess user's perceptions of autonomous vehicles. The vehicle they modelled is a small autonomous passenger boat to be deployed in Amsterdam, NL. They found that trust, stress, and perceived risk are dependent on the complexity of the environment, but there was no significant difference regarding whether the boat is automated or controlled by a human. In a study performed within the Autoferry project in Trondheim, Norway (Pantelatos et al., 2023) passenger survey responses indicated that a "human host" should be available in case of evacuation, or if somebody falls overboard, to maintain order and to reduce the occurrence of abusive behavior. In this instance, 60% of the respondents agreed that it would be sufficient for this human host to be available at quay areas, a result that might be explained by the very short travel distance for that ferry. In a second example of Norwegian research, the AutoSafe project, a shore-based "safety supervisor" was envisioned that would have the capacity to reach the ferry using another boat, and once on board, assist the passengers and possibly steer the ship (Thieme et al., 2023). In a third Norwegian case providing safety analyses for autonomous ferries in the Møre & Romsdal municipality (Pobitzer et al., 2022), travel distances were longer. These researchers emphasize that mustering and evacuation in emergency situations is particularly difficult to solve with automation technologies, and for that reason, an onboard "safety officer" will likely be necessary for the foreseeable future. Although steering of the ship could be performed remotely, these researchers argue, the safety officer may fill an important role in enhancing the situation awareness of remote operators. Similar conclusions are drawn by Wróbel et al. (2017) who performed "what-if" analyses on 100 prior accidents to investigate possible consequences of increased automation. These authors state that although the probability of certain scenarios (such as groundings and collisions) may be reduced by automation, crews will still be valuable for reducing the consequences of accidents, and the authors emphasize the importance of professional experience for handling unforeseen events. Similar to the case of remote operators, the competency demands on a "driver" of an autonomous vessel are expected to increase, covering technical and engineering skills associated with automation technologies (Orfanou et al., 2021).

Johnsen et al. (2022) argue that ship design should be approached in a systemic, user centric way, covering both operations and the infrastructure that surrounds it, since the safety of passengers on automated ferries depends on interactions between on board sensors and systems, remote operators and rescue services. When humans and automated processes share the navigation and control responsibilities of an automated ship, such as the case of remote human supervision or control, the human-automation interface must provide the human with adequate situation awareness. This means that information from the ship about its status and surroundings must be transferred and presented to humans in a timely manner, while supporting cognitive abilities, so that the necessary actions can be taken at the right time (Ahvenjärvi, 2016; DNV-GL, 2018; Fjørtoft and Rødseth, 2020). Good design and efficient human-machine interfaces have the capacity to improve communication, workload, situation awareness and decision-making in remote operations (Kari and Steinert, 2021), and interfaces are also needed that provide rescue operators with relevant data, such as the type of incident and the status of safety systems, propulsion and passengers (Pobitzer et al., 2022).

Technologies to allow safe evacuation in operations with reduced manning has been identified as a significant research gap (Borgen et al., 2022) and several solutions are proposed in the literature, where differences in the technological approach often relate to local operational conditions (such as distance to shore). In terms of overall ship design and layout, some authors suggest one-deck open layouts (Borgen et al., 2022; Pobitzer et al., 2022) as a way of improving overview and simplicity, e.g. for the sake of mustering and wayfinding. On the topic of evacuation methods, Borgen et al. suggest two potential solutions. One possibility is to install rafts that can be easily activated by "safety manning" on board and that do not require further adjustments (e.g. with lines) after activation. Another possibility for ferries operating close to shore is to dispense with emergency rafts altogether and instead offer functionalities that would circumvent the hazards related to emergency rafts (Johnsen et al., 2022; Thieme et al., 2019), such as relying on safe spaces (Pobitzer et al., 2022), remaining afloat via hull compartmentation and floatation devices (Thieme et al., 2023) and navigating to the closest landing point autonomously. In their analysis of Norwegian ferry automation prospects, Pobitzer et al. (2022) state that while automation of evacuation system activation (e.g. slides and rafts) has come a long way, mustering and boarding of life saving vessels are activities that will still often require assistance from the crew. In addition, Borgen et al. (2022) and Thieme et al. (2023) acknowledge that evacuation solutions that omit life rafts are not permitted by current regulations.

There are few examples of previous research that go into details regarding information for passengers and solutions to enable passenger-shore communications. In a study on hazards and risks of autonomous ferries in Norway, Johnsen et al. (2022) propose that passengers should be able to obtain information on the ferry's status, predicted future states and actions that the passengers need to perform, and the authors mention the need for supplying safety information (such as rescue routes and procedures) before boarding. In some cases, emergency push buttons are envisioned for allowing passengers to alert a ROC to emergencies on board (Amro et al., 2020; Thieme et al., 2019). Amro et al. (2020) describe a solution where the button is specified as an indication of a passenger related emergency and is expected to either initiate an intervention from an emergency control team or give human operators full control of the ship.

Scenarios where manned, remotely controlled and unmanned vessels interact in the same environment are likely, and could lead to safety issues relating to communication, compatibility and coordination (Kim et al., 2022). For example, reducing the crew on a passenger ferry might reduce its capability to assist other ships in emergency situations (Jalonen et al., 2017), such as its ability to pick up survivors from the water (Wróbel et al., 2017). However, Jalonen et al. (2017) propose that nearby automated ships could have positive contributions to emergency management, e.g. by supplying video and sensor data to authorities. In relation to external assistance, Pobitzer et al. (2022) propose that solutions need to be developed that allow rescue ships to dock to autonomous vessels in distress and transfer rescue personnel in a safe manner, and Johnsen et al. (2022) mention the need for rescue services to be able to control a damaged automated vessel (e.g. by towing).

1.1.4. Organization of Swedish rescue services

Both internationally and in a Sweden national context, a ship's location will determine who is responsible for rescue operations. Internationally, this is regulated by an international Search and Rescue (SAR) plan, specifying how responsibilities are distributed on international waters (International Maritime Organization, 1998). The organization of rescue in near coastal waters is defined by the state's regulations.

The traffic types considered in this study sail on waters labelled as either municipal or state, which governs which party is responsible for accident management. Normally, Swedish state water includes everything except waterways, canals, ports, and lakes other than the large lakes Vänern, Vättern and Mälaren (Lag om and mot olyckor, 2003). However, for certain water areas in Stockholm, Gothenburg and Karlskrona, the water category is defined based on agreements between the local rescue services, the Swedish Maritime Administration (SMA), and the Swedish Coast Guard (Storstockholms brandförsvar, 2021). Accidents on state water are managed by an authority designated by the government. On municipal water, the municipal rescue service is responsible (Lag om and mot olyckor, 2003). Three actors within the rescue organization network are presented below, but additional resources may also be involved, such as the Swedish Coast Guard, the Swedish Armed Forces or resources from neighboring countries (Swedish Maritime Administration, 2022).

1.1.4.1. JRCC. The Joint Rescue Co-ordination center (JRCC) is part of SMA and includes sea and air rescue, two teams working side-by-side (Swedish Maritime Administration, 2021b). Within the present study, JRCC refers to maritime rescue operations. A distinction is made between life-saving interventions and environmental emergencies, where the first belongs to the JRCC's responsibilities and the second to the Swedish Coast Guard (Swedish Coast Guard, n.d.; Swedish Maritime Administration, 2021b). Furthermore, JRCC coordinates rescue operations on state water, but also assists when accidents occur on municipal water.

1.1.4.2. MIRG. There are three Maritime Incident Responses Groups (MIRG) teams in Sweden, located in Stockholm, Gothenburg and Karlskrona. They consist of specially trained firefighters (employed by the municipal rescue services) who are prepared to do smoke diving and lifesaving operations on ships. Apart from these capabilities, MIRG is prepared to assist during a ship evacuation, and can also help with communication with the coordination center (Swedish Maritime Administration, 2021a, (Swedish Maritime Administration, n.d.)). When accidents occur on municipal water, the local rescue service will coordinate instead of JRCC. Since MIRG is part of the rescue services, the operations manager can be someone from the MIRG group.

1.1.4.3. SSRS. The Swedish Sea Rescue Society (SSRS) is a non-profit association for sea rescue. There are stations along the Swedish coastline with rescue craft and volunteers working to ensure safety at sea (Swedish Sea Rescue Society, n.d.). Operations include rescue missions, preventive missions, medical transport and environmental rescue; the units may receive alarms from either the rescue service or JRCC. A rescue mission is a mission where there is an acute danger to life and the resources of SSRS (e.g. rescue ship and crew) are made available to assist. SSRS works according to a national strategy developed together with the SMA.

Based on the national response program (Swedish Maritime Administration, 2022), geographical location of rescue units and response times, the assumption was made in the present study that for an incident requiring the evacuation of a near-coastal passenger ship, it is likely that SSRS will reach the ship in distress before MIRG.

2. Method

Due to the limited amount of existing literature on ship evacuation in near-coastal traffic, emphasis was placed on investigating current evacuation processes in different operational settings. Data was collected through field studies and interviews. This data was used to create a process map for evacuation of a passenger ship in near-coastal traffic, and the results were used as the basis for a workshop where evacuation stakeholders discussed the implications of increased automation.

2.1. Scope of the study

Since this study was centered on the role of people in an emergency evacuation, the results emphasize crew actions and consequences of the presence or absence of crewmembers, not potential technical solutions or whether the ship is autonomous, automated, or remote-controlled.

As previously mentioned, there is no current agreement on safety regulations for unmanned ships; it is still uncertain what future regulations will allow. For this reason, this study included scenarios that are not covered by current regulations.

This study was carried out in Sweden, involving Swedish operators and actors in emergency response. The results may not be directly transferrable to other regions in terms of the current state mapping, but the identified needs are expected to be very similar regardless of local rescue organization structures.

The scope of the study was limited to passenger ships in near-coastal traffic, including both road ferries transporting passengers and vehicles as well as public transportation ships transporting pedestrians and cyclists.

2.2. Research questions

- What are the tasks fulfilled by crews currently manning ships in coastal passenger traffic?
- Which actors besides the crew are involved in an emergency evacuation?
- Which tasks performed by the crew or other actors would need to be substituted or modified if ship manning is either a) reduced to one person, or b) removed or relocated?

2.3. Mapping of near-coastal ship evacuation: current state

Current practices for ship evacuation were investigated to uncover what challenges must already be faced by operators and rescue organizations today – challenges that may increase or diminish as automation gains ground.

2.3.1. Field studies

Ships operating in Swedish near-coastal environments were visited between September 2022 and March 2023. Circumstances differed with each visit and are summarized in table 2 below. Each visit included interviews with crewmembers and managers, primarily focusing on current practices and challenges of evacuation. Crewmembers were also asked to demonstrate environments and evacuation-related equipment onboard. Serious accidents on the ship types included in the study are rare in a Swedish context, which means that crewmembers mainly provided input based on general professional experience such as previous passenger interactions, minor incidents, safety training and drills. Researchers took note of crew tasks, evacuation systems and onboard environments. Visits were documented through notes and photographs taken during visits. The study involved 14 crewmembers (11 male and 3 female) and 4 managers (3 male and 1 female)

2.3.2. Interviews with rescue organizations

To complement the field studies, interviews were carried out with Swedish rescue organizations. Representatives from four organizations were interviewed – three through video calls and one during an on-site visit. Interviews were recorded and manual notes were taken. Interviews were semi-structured, covering the following topics:

Table 2
Field study summary.

	Type	Max passenger and vehicle capacity (rounded)	Crew	Voyage
Ship A	Public transportation	300 passengers. Bikes are common and during rush hours, there may be up to 80 bikes onboard.	Captain and deckhand.	Shuttle traffic in harbor area. 4 min voyage.
Ship B	Public transportation	300 passengers. Bikes are common and during rush hours, there may be up to 80 bikes onboard.	Captain and deckhand.	Shuttle traffic in harbor area. 4 min voyage.
Ship C	Public transportation	450 passengers.	Captain and deckhand.	30 min voyage in harbor area, several stops along line.
Ship D	Public transportation	150 passengers.	Captain, second officer and deckhand.	35 min voyage in archipelago, several stops along line.
Ship E	Public transportation	350 or 500 passengers, depending on crew size.	Minimum: captain, two deckhands, one cafeteria. Maximum: one additional cafeteria and a second mate.	1.5 h voyage in archipelago, several stops along line.
Ship F	Road ferry	300 passengers and 60 vehicles.	Captain and deckhand.	13 min voyage between island and mainland.
Ship G	Road ferry	400 passengers and 40 vehicles.	Captain and deckhand.	6 min between island and mainland.

- Organization: responsibilities and roles
- Rescue missions: common missions, experiences with passenger ships, near-coastal experiences
- Communication during missions: especially focusing on near-coastal passenger ships
- Information needs
- Collaboration between actors
- Possible implications on their work following increased automation

2.4. Analysis & modeling of evacuation tasks

Field study data was entered into tabular form and subjected to a process of analytical coding (Merriam and Tisdell, 2015), where the materials were examined for common themes. This resulted in the coding categories:

1. Technical data (ship type, number of passengers, vehicles allowed)
2. Environment (operational setting, waters)
3. Evacuation equipment
4. Crew and roles
5. Evacuation scenarios
6. Communication
7. Evacuation preparations
8. Involvement of passengers
9. Training
10. External resources.

In the next step, the thematically sorted field study data was examined to single out work tasks in the process of evacuation, and the rescue organization interview notes were also coded according to themes representing their respective tasks. To grasp the relations between tasks for each actor, the whole evacuation process was visualized with arrows representing task dependencies. Finally, a task analysis was produced. Task analysis has been referred to as one of the primary and most enduring tools of human factors (Hollnagel, 2021) and is a common starting point for human factors inquiries (Stanton, 2006), allowing the analyst to grasp what people must do in order to achieve a certain goal or objective (Hollnagel, 2012). In a Hierarchical Task Analysis (HTA), overall operational goals are broken down into subtasks, making it possible to analyze and discuss their interrelations and the conditions under which they are carried out (Rausand and Haugen, 2020). A task analysis is often used to produce normative results (i.e., descriptions of how work should be carried out), but it can also be used in a descriptive manner, to understand how tasks are implemented in practice. Task analysis can also be used in a formative manner (to envision new ways of working) (Ostrom and Wilhelmsen, 2019), which was the purpose behind employing the method in the present study. The original aim of HTA was not only to allow the description (or prescription) of manual work tasks, but also to facilitate the investigation of teamwork, interaction between people and technologies (Stanton, 2006), cognitive work tasks involved in goal attainment, such as monitoring, anticipating and planning, (Salmon et al., 2010), and the organization of tasks in work systems including both people and technical artifacts (Hollnagel, 2021). To be effective, a task analysis should examine interrelations between human operators, equipment and the environment (Ostrom and Wilhelmsen, 2019). This mirrors the objective of the present study, which was to examine passenger ferry evacuation from a sociotechnical perspective, i.e. how people and technologies function together, in a social and organizational context, to produce desired outcomes (Hollnagel and Woods, 2005).

Performing an HTA typically involves identification of goals and subtasks, as well as plans, relations between tasks such as procedures, selection rules or time-sharing principles (Hollnagel, 2012). The purpose behind employing the HTA method for the analysis in this instance was, however, not to build a complete HTA representation of the tasks carried out. The purpose of the first iteration of task analysis was to support the planning of a workshop involving stakeholders in ship evacuation, further described below. The primary focus of the workshop was to discuss future automation scenarios in relation to evacuation, but notes taken during the workshop could also be used to complement earlier data on evacuation tasks. The purpose of the second iteration of the task analysis was to provide a structure for the analysis of qualitative data presented in this paper. For illustration, one instantiation of this task analysis (for evacuation to another ship) is also presented in the results. To fulfill these purposes, HTA was applied in a simplified manner, only describing goals, subtasks and an exemplified (but not necessarily generic) order of task execution. As a stop rule (Stanton, 2006), tasks were only broken down to a level where further decomposition would not reveal any more findings that could be related to the case of crew reduction and increasing automation. Sorting qualitative data under the goals and tasks represented by the HTA made it possible to understand how the fulfillment of evacuation tasks may be influenced by the context of a ferry accident, the many different conditions that may shape task performance, and to reason about potential implications of automation for the task.

2.5. Stakeholder workshop

The stakeholder workshop had an emphasis on increased automation and the participants were asked to discuss different topics based on their professional experience. The workshop was held in April 2023. The participants (3 female and 5 male) had the following profiles:

- Human factors researcher (workshop facilitator)
- Risk and fire engineer, partially involved in the study
- Rescue coordination operator, rescue authority
- Rescue operation leader, voluntary rescue organization
- Maritime safety specialist, maritime authority
- Safety manager, shipping company operating public transport in archipelago and harbor area
- Operation and district manager, shipping company operating road ferries
- Ship technician with ship evacuation experience, shipping company operating road ferries

The workshop consisted of three main blocks:

1. Introduction: main risks in the current process of ship evacuation. Opportunity for the participants to share any direct thoughts, opinions, or expectations.
2. Automation scenario discussions – besides discussing risks and possibilities with each scenario, variables such as ship type, surrounding traffic and environment, passenger demography and weather were introduced gradually. The facilitator led the conversation, but participants were allowed to discuss the topic quite freely.
3. A summarizing session, where participants were asked to try and define what is important to consider as automation progresses within each traffic type – what automation scenarios could be possible?

2.5.1. Creation of scenarios

Four hypotheses for different crew scenarios were created to spur discussions during the stakeholder workshop. These scenarios are similar to the IMO levels of autonomy for MASS (International Maritime Organization, 2021), with an emphasis on the number of crewmembers onboard. The purpose was to focus the discussions on the ability to assist passengers while staying open to different

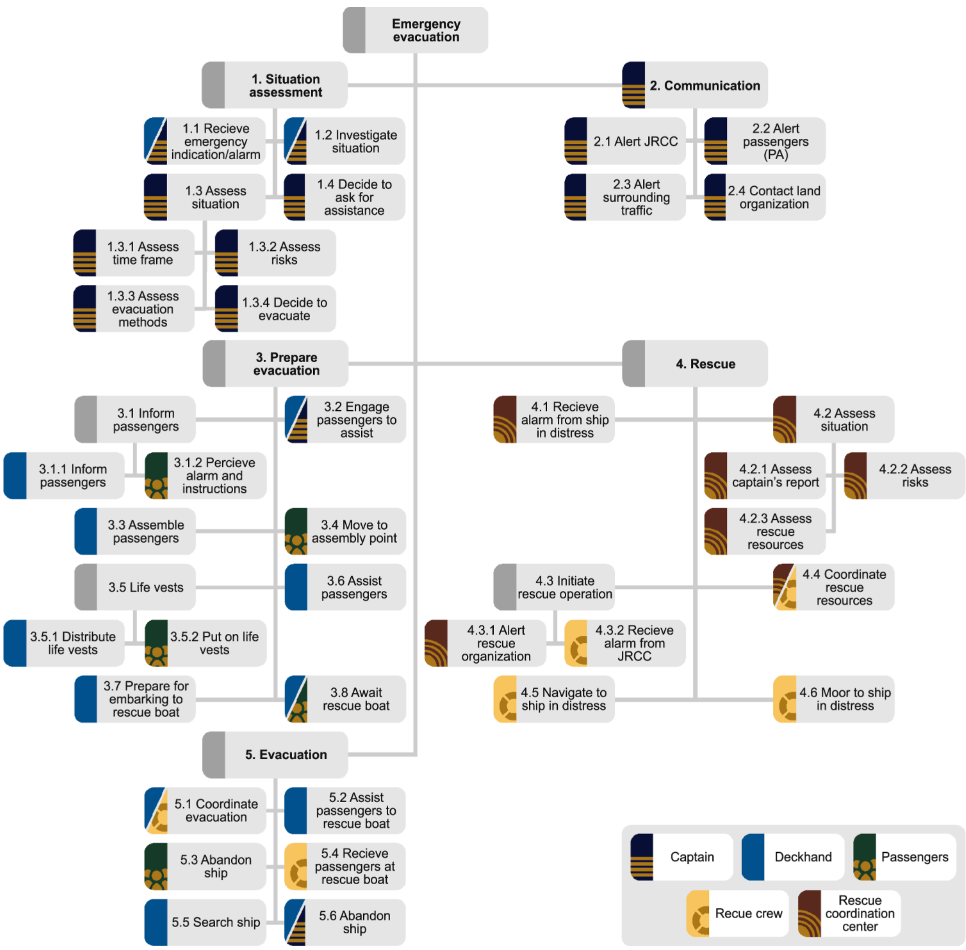

Fig. 1. Simplified HTA for evacuating a passenger ship to a rescue ship.

technical solutions. Titles of crewmembers were not defined, again with the purpose of keeping the discussion open to different solutions. The four scenarios were:

1. Ship with automated functions and **two crewmembers** onboard. Crewmembers can take control of the ship.
2. Remotely controlled ship with **one crewmember** onboard (the crewmember is not necessarily a licensed mariner and could instead have gone through an on-the-job training program).
3. Remotely controlled ship with **no crewmembers** onboard.
4. Fully autonomous ship with **no crewmember** onboard.

The following delimitations and assumptions were made:

- Current regulations regarding the number of crewmembers onboard were not considered
- Increased automation will not result in an increase of crewmembers

In addition, four traffic types were distinguished and discussed for the scenarios:

- Road ferry – mainly people in cars
- Passenger ship – archipelago
- Passenger ship – harbor area
- Shuttle ferry – pedestrians and possibly bikes

3. Results

This section presents the results of the analysis of tasks involved in ship evacuation, based on a simplified application of Hierarchical Task Analysis (HTA) (Stanton, 2006). The main objective of the workshop was to discuss potential future evacuation prospects in scenarios with increasing automation. For that reason, findings from the workshop are presented at the end of each section. In addition, some findings were recorded that do not directly relate to the evacuation process, but that nevertheless are relevant for future automation-related safety considerations. These findings are presented in the final section of this section.

According to interviewees, the process to evacuate a ship can be considered an extreme operation and something that may be more dangerous than keeping the passengers on the ship. Many variables affect the decision to evacuate and the destination, for example to life rafts, to another ship (rescue ship or other passenger ship), or to land. Fig. 1 provides a simplified overview of the tasks related to *evacuating passengers to a rescue ship*. While the practical details of completing each task will differ for other evacuation cases, the tasks themselves are generic. The main goal, emergency evacuation, was broken down into five tasks:

1. Assessment of situation
2. Communication
3. Prepare evacuation
4. Rescue operation
5. Evacuation

The tasks were further divided into 1–2 levels of subtasks, color coded according to which role the task belongs to. A detailed explanation of these tasks/sub-tasks is provided in the following sections.

3.1. Situation assessment

If an emergency is indicated (e.g. through a fire alarm) or an accident occurs, the ship's captain must assess the situation and decide on the best way to keep the passengers safe – either to let them stay onboard or to abandon the ship. According to interviewees, this decision must be weighed against several factors, such as the amount of time available, the condition of the ship, weather conditions, the number of passengers, and available rescue resources (including nearby ships). These are conditions that need to be monitored continuously during an accident, and decisions rest on the captain's competence, professional experience, and local knowledge concerning the area and its traffic. Certain aspects of safety are considered before the journey begins, such as the manning level appropriate to the current operational conditions (e.g. weather). Among the visited ships, the archipelago ships were generally the ones most exposed to weather and wind, while the road ferries and harbor shuttles were relatively protected. If traffic is reduced due to poor weather conditions, then the ships that can still operate may be able to double their manning with help from the canceled ship's crew. The characteristics and capacity of a ship are largely the determining factors, but one crewmember on an archipelago ferry said:

> *"Even if the ship itself can manage a certain wind, you have to consider if the team is also able to manage that situation before you head out."*

When discussing the possibility of remote operation or supervision during the workshop, a participant representing a rescue organization stated that the captain on board has something of a "sixth sense" when navigating – understanding the situation with regard to the ship itself and its context, and how that understanding transfers to operational decisions – and it was questioned if a similar capacity could be reproduced in a remote-control room. As an example, it was mentioned that Joint Rescue Co-ordination center (JRCC) operators are required to hold a Master Mariner's Certificate, something that helps them form a "mental image" of the state of a vessel in distress, but that it can still be very difficult to form that image remotely.

3.2. Communication

Nearly all visited ships (and their sister ships) operate with only a crew of two – captain and deckhand. In case of an emergency, crew interviewees stated that the captain will be occupied with external communication and will not be able to leave the ship's bridge. This makes the communication between the captain and deckhand very important, because it is often not possible to supervise the whole ship from the bridge. The exception to this comment is road ferries, where the view from the bridge is significantly better. Regarding communication, one deckhand stated:

"During drills, the communication [with the captain] works very well, but in a real situation, it would be very lonely down here."

The captain will contact rescue organizations in case of an emergency and is also expected to contact the ship's Designated Person Ashore[1] (DPA), but one crewmember on a road ferry stated that 'to be honest, that is our last priority'.

The captain will use a Public Address (PA) system to address the passengers and provide information about the incident. Given that the deckhand will move amongst the passengers, this person will have to answer questions and supply additional information, such as detailed guidance around movements, mustering, and safety equipment. It was mentioned by one crewmember on a public transportation ship that the information shared and the wording used will be weighed carefully, so as not to spread unnecessary fear.

Participants in the workshop stated that if a ship was to be operated without an onboard crew, how passengers would react to emergency information is an open question. One participant brought up a real-life example from an incident where the general alarm had sounded for a couple of seconds without any reaction from the passengers, but where everyone listened as soon as the captain explained what had happened.

3.3. Prepare evacuation

The work done by the deckhand to handle all passengers and perform other tasks related to the emergency was described as very demanding by crewmembers, and they emphasized the importance of having somebody physically present in case of an emergency. A deckhand on a public transportation ship described how for one ship, responding to an accident will involve informing the passengers, then preparing the Marine Evacuation System[2] (MES) station on the upper deck, then going back down to the passengers and assisting them when moving up the stairs to reach the MES. MES systems are sometimes activated by a simple push of a button, but additional rafts may need to be pulled in towards the landing raft using lines. Another crewmember on another public transportation ship said that in one drill, they found that many passengers were not able to get the life vest on correctly and that this activity may also require the deckhand to assist. Deckhands should keep track of the number of passengers on board, but it was mentioned during a visit on a public transportation ship and on a road ferry that this task will often not be performed in full. For road ferries, the number of vehicles is the primary concern and the crew will likely not know the exact number of passengers, given that some of them may be out of sight within vehicles. The fact that passengers often remain in the vehicles on these ferries may, however, present other problems, such as convincing them to leave their cars and belongings behind. Lastly, the deckhand was described by one interviewee within public transportation as "the captain's eyes on deck", meaning that the deckhand also needs to supply the captain with information about conditions on deck, in addition to performing any other orders such as surveying the accident state or the condition of the ship.

Field study interviewees stated that, given the high demands placed on the deckhand, they will likely need assistance from a few passengers in case of an emergency. Perceptions of how that would work seemed to differ. One way mentioned on a road ferry is to utilize the PA system, for example to find healthcare competence on board. The PA may, however, be difficult to hear for passengers in cars, or because of the murmur from the crowd. One crewmember on another road ferry said that they would grab someone that looks *'solid and calm'*. A crewmember on a public transportation ship said:

'You must order someone to help, not ask. We have tried asking passengers and they become terrified from being given responsibility.'

A third interviewee on a road ferry commented:

'Hopefully someone would volunteer to help – how would we know who is capable of what?'

Should automation become more common on these ships, workshop participants commented, it seems likely that any crew working onboard would still need special emergency training, similar to the situation today. Some participants were convinced that this person should still be required to hold a master mariner degree, while others imagined something similar to flight attendants with on-the-job-training. Regardless, it was commonly agreed that any personnel working on board an automated ferry would be subject to intense pressure in case of an emergency.

[1] A shipping company representative responsible for overseeing the vessel's safety compliance.
[2] A slide or chute leading to an inflatable life raft.

3.4. Rescue

In case of an emergency at sea, many different actors may become involved. The form of coordination and, in some cases, who becomes involved, differ depending on the waters where the ship is located and if there is any danger to life. The description presented here is applicable to Sweden. Organization, mandates, and resources will vary internationally.

3.4.1. Seeking outside assistance

According to an interviewee from a rescue organization, there are nearly no ships equipped with automatic distress signals today, so accidents will always be reported by an individual through SOS Alarm (the local emergency telephone operator) or over Very High Frequency (VHF) radio on channel 16 (call sign Sweden Rescue). This person may be queried by the JRCC to provide further information about the accident. JRCC monitors a lot of general communication over the VHF, and on a summer day, the radio can be quite busy. For this reason, a rescue organization interviewee explained, it will not always be the case that the JRCC perceives a distinct 'Mayday' call. Instead, they may react to the tone of the person calling and conclude that something has happened.

Both interview data and governing documents (Storstockholms brandförsvar, 2021) indicate that rescue organizations will collaborate in a similar way, regardless of the type of water, only with different organizations as lead. Even though the main organization responsible for leading a rescue operation may differ, a crewmember operating on municipal water said that they might still contact Sweden Rescue (JRCC) instead of calling SOS via the emergency phone number. The Vessel Traffic Service (VTS) was also mentioned as an organization that could provide assistance. Although emergencies are not their responsibility, the interviewed crewmember could not imagine that the VTS would not assist. In the case of the fire on Almirante Storni in 2021, it was the VTS that answered the initial alarm and then alerted JRCC (Swedish Accident Investigation Authority, 2023).

The traffic surrounding near-coastal passenger ferries varies from leisure boats to various commercial vessels, and every visited crew pointed out specific actors in their area that could assist in an emergency, suggesting that there are strong local networks. On this topic, one crewmember from a public transportation ship said:

> *"If we call on channel 16 that something happened, there are many that would respond, especially in the harbor area."*

This kind of assistance is also mandated internationally as well as by Swedish Maritime Law, which states that a captain who is notified that someone is in distress must provide all the help that is possible (under safe circumstances) to save the person (International Maritime Organization, 1974; Sjölag, 1994). In addition to the external actors in the area, all visited ships also had additional ships from the same shipping company nearby.

3.4.2. Emergency assessment

An interviewee working with rescue coordination said that when an alarm is received from a ship in distress, their first task is to assess the situation, e.g., how the situation might develop and how much time is available before it worsens. Establishing a common view of the situation was mentioned by a rescue personnel interviewee as one of the main challenges with rescue operations, e.g., if the crew's and JRCC's view do not coincide. If these stakeholders interpret the situation differently it may result in a conflict of priorities between saving lives and handling a fire. According to the interviewee, the professional knowledge of the endangered ship's crew is extremely important and the captain's assessment is normally not questioned. The ship's DPA is usually involved and can assist with some information as well. For instance, the DPA may know how many passengers are onboard. However, for near-coastal traffic, an interviewee stated, the chance that the DPA knows the number of passengers is very small.

As soon as rescue units reach the scene, an on-scene-coordinator (OSC) is appointed, normally a person from one of the rescue organizations. The responsibility is still with JRCC, but the OSC can act as their extended arm. Other on-scene information sources must be treated more critically. An outside observer may, for example, report something that looks dangerous from the outside, but is something the crew is familiar with and knows how to manage. The situation may also be reversed, as explained by another rescue organization interviewee, speaking about the importance of competent people assessing the situation:

> *Something that we have learned over the years is that we should not make any real assessment until there is someone competent at the scene. For instance, two ships collided. A man [on a third ship] with a VHF says to us "Everything looks fine, they are staying in the boats" and made the whole situation less dramatic. This can make you consider cancelling some resources, but in reality there may be two severely injured people on the boat. So surrounding traffic can give some information, but the assessment must be done by someone with the right competence.*

Workshop participants voiced similar concerns when discussing scenarios with automated ferries. For example, if information about fire detection was relayed to the JRCC, that information would not be complete on its own. They would also need to know information such as the number of passengers, where they are in relation to the fire and if the ship is about to run aground. Another example brought up in these discussions was that when a ship is taking in water it may move very calmly, which may cause the passengers to think that all is fine. The problem of not having a professional counterpart on board was emphasized by a participant from a fire and rescue organization:

> "*When we are on our way out, we are completely depending on having a counterpart who can tell us what things look like and how they [the crew] work. I would doubt sending down my personnel if there is no one there to help us making a risk assessment. […] What would the reactions be if there is no one to calm down and instruct [the passengers], and what would we [fire and rescue organization] face when we are sent out to that situation. Perhaps we cannot even do our job if we are faced with passengers and their need for information.*"

As stated by one participant representing a rescue organization, if you do not trust the competence of the person alarming, you might have to initiate a full rescue mission every time, and the consequence of that may be that the threshold to initiate an evacuation could become lower.

On the topic of emergency alerting, a workshop participant suggested that several passengers on an automated ferry might call the SOS number at once, with the risk of confusing the situation, and concerns were raised that passengers calling SOS might give an 'emotionally influenced assessment or description of the situation'.

3.4.3. Initiate rescue operation

The Swedish Maritime Administration (SMA), through the JRCC, has access to Search and Rescue (SAR) helicopters and pilot boats for immediate assistance in case of an accident. JRCC also has a strong authority and could, in principle, order any leisure boat to assist. In the case of near coastal traffic, response can be very quick since travel times are short. This was mentioned by an interviewee involved in rescue coordination as a possible source of issues with miscommunication and coordination. For instance, people that are injured could be taken to the wrong location if communication fails.

Out of all the seaborn resources, a rescue personnel interviewee stated that Swedish Sea Rescue Society (SSRS) is often the first to arrive at the scene of an accident. Staffing of the SSRS stations can be very different in summer and winter time. A station that would have nine people on standby in the summer might only have two in the winter. The interviewee also talked about the difference in numbers of people responding to an incident:

> *You are always two at least, but with only two people you can't do that much. If you're three you can do a good deal. […] If you're only two, there is one driving and one running around on deck. If you are three, you can have one go over to the other ship and manage people there. If you're only two, no one can go over. […] That will leave a lot for the crew to deal with on their end.*

People management was pointed out by interviewees as a difficult task in rescue missions, but another aggravating circumstance can also be the shape of the ship's hull and what that means for the chances of docking against the ship.

3.5. Evacuation

Several means of evacuation were pointed out by interviewees, where the situation and the number of passengers onboard governs the chosen method. All visited ships have MES installed and, in most cases, they can be launched from the bridge. MES are perceived by crewmembers as quite easy to launch and use and according to one shipping company operations manager their efficiency has been proven, but crew interviewees stated that evacuation using MES would probably not be their first choice. For example, one crewmember stated that *"Launching a MES in the harbor where we operate seems very unlikely."* Another crewmember working on an archipelago ship said:

> *"If you have the kind of control of the ship where you can ensure that the MES is protected from wind, then you are likely in a situation where you could evacuate in other ways than using the MES."*

Instead, crewmembers argued, it would be preferred to evacuate to another ship, and many interviewees pointed out the possibility of calling on ships in the network of surrounding traffic. On the topic of rescue ships, a crewmember mentioned that the design of one particular ship made it difficult for rescue ships to moor to it. This was also mentioned by a rescue organization interviewee, specifically pointing out an angled hull side as an aggravating circumstance. Apart from evacuating to other ships, the other preferred method mentioned by crews is to evacuate directly to land.

In relation to the chosen method of evacuation, workshop participants discussed decision-making in the evacuation process. Here it was mentioned that boarding the life rafts is not necessarily a safer option than staying onboard, and that the passengers are not desired to make certain decisions on their own, such as embarking on life rafts when doing so would in fact expose them to greater risk. One participant also added, partly humorously and partly seriously, *"or is it a risk in itself if the passengers knew that the life raft is a risk?"*.

3.6. Future operational considerations

Participants in the workshop discussed the potential conflicts associated with increased automation – improving or maintaining passenger safety vs saving personnel costs. In a scenario where automation is introduced alongside a crew that remains on board, it was perceived that new technologies could increase safety at sea, e.g. by relieving the crew of some tasks in case of emergency. However, the participants argued, this could also cause a decrease in competence, e.g. knowledge of ship and onboard systems – something that was strongly associated with the successful outcome of managing an emergency.

For the other scenarios, where automation would replace or relocate some or all the crewmembers on board, the participants found it less likely that safety would be improved. For the case where an operator supervises the ship from a Remote Operations Center (ROC) while a "host" of some kind remains of the ship, concerns were raised about what would happen if communications were lost, and how that would affect the command structure.

Completely automated passenger ships without any onboard crew were only deemed suitable by the workshop participants for 'very short distances and very few passengers'. Another suggested constraint was a ship's sensitivity to weather conditions, and whether an automated ferry should only be out when the weather is good, so that an emergency situation would not be escalated by difficult conditions. One participant found it very unlikely that the crew would ever be reduced below two persons for archipelago traffic, specifically pointing to weather and wind exposure and the high volume of tourists among the passengers as reasons. While increased automation may lower the salary costs of shipping companies, the participants saw a risk that society's costs may increase due to increased resource demands by rescue organizations, or due to a larger volume of unnecessary rescue missions. The question of increased autonomy and changes to shipboard work practices was described by participants as a sensitive topic for some seafarers. However, one operations manager stated that shipping companies already struggle to find personnel, meaning that ships may have to be automated regardless of whether people prefer it or not.

4. Discussion

Previous studies of passenger ferry evacuation have demonstrated that the process of abandoning ship may be extremely challenging, both for the passengers and for the ship's crew (Jørgensen and May 2002; Sarvari et al., 2019). Preparing and executing an evacuation may be obstructed by physical barriers, such as overcoming obstacles or moving between decks, and also by barriers that are cognitive in nature, such as issuing understandable instructions, perceiving those instructions, or understanding how to navigate the ship's interior (Burgén et al., 2023). In a situation like this, the crew needs to be prepared - and equipped - for assisting passengers with varying capabilities, taking into account factors such as age, mobility and impairments (Burgén et al., 2023). This work explores how such activities may be affected by technical advances allowing a greater use of automation in near-coastal passenger ferry traffic, changing or possibly replacing the crew's work tasks. Findings confirm prior observations in the relatively sparse literature dealing with human factors in the evacuation of larger passenger ships, showing that the evacuation process depends on a combination of many different capacities – a multitude of skills, technical equipment and forms of collaboration. In the following sections a selection of crew and passenger evacuation activities are discussed in relation to different levels of crew reduction and associated changes in operations.

4.1. Crew reductions and task allocation

The interconnected nature of humans, technologies, and tasks emphasized by Dekker and Woods (2002) in their criticism of common task allocation schemes for automation is apparent in the context of small passenger ferry evacuation. The deckhand performs a wide variety of functions in an accident scenario, both in contact with the passengers and in interaction with the captain, employing operational experience as well as a multitude of technologies. Many proposed automation solutions include one crewmember on board in the role of a "safety host" or similar, with the main responsibility of guiding and assisting passengers, communicating with a land-based operator who oversees and guides the response (Goerlandt and Pulsifer, 2022; Mehta et al., 2021; Veitch and Alsos, 2022). Previous research in other domains, e.g. for rail, has shown that aside from the more obvious tasks involved in accident response, operational personnel will often perform many other important safety related tasks that can easily go unnoticed (Jansson et al., 2023). In this scenario, further research is needed to assess the risk of task overload for the safety host, making sure that any automation solutions implemented to offload this actor are usable and do not add new tasks, even if they substitute others. Second, the interaction between the safety host and land-based personnel demands more in-depth studies. Communicating without being in the same location and sharing the same references may prove more difficult and require more frequent interaction, thus increasing the workload. When the safety host is the only crewmember on board, this person may also be required to interact more with rescue resources arriving at the scene.

Regarding command, the ability to support and guide a safety host may be different for land-based personnel, compared to an on board captain. The tasks of the captain – e.g. navigating and maneuvering the ship – are the main targets of many proposed ferry automation solutions (Fjørtoft and Rødseth, 2020; Pobitzer et al., 2022), and it has previously been observed that moving the captain to land, and moving the role more towards supervision than control, may cause issues commonly related to automation, such as a lack of situation awareness and degradation of manual skills (Johnsen et al., 2022), lacking sense of ship motions (Wahlström et al., 2015), boredom and fatigue, as well as periodically increased workload (Kari and Steinert, 2021), communication issues and information overload (Kari and Steinert, 2021; Strauch, 2018; Wahlström et al., 2015), while also demanding new competencies (Orfanou et al., 2021). Indeed, the data suggests that effective decisions and actions on behalf of the captain depend heavily on both manual and theoretical skills, knowledge of local operational conditions, and not least, an ability to adapt actions to contextual factors, such the ship's characteristics and state, weather conditions, the number and state of passengers, nearby traffic, and opportunities to reach land. The ability of humans to adapt to unforseen events is key in case of an accident (Stene, 2018) and is deeply associated to professional experience (Wróbel et al., 2017). The data suggests that many decisions, such as deciding whether abandoning the ship is actually the safest option, rest on a thorough understanding of the situation at hand. In this context, research must show whether sensors, cameras and communication equipment can provide a remote operator with sufficient information to support a similar decision-making process, and also whether the ability to engage in such a process can be reproduced in remote operators, should they not have the same seafaring experience.

Maintaining situation awareness and readiness are issues in which the design of technical equipment, working environments and work roles clearly go beyond mere task allocation, and consequently, where reproducing the professional characteristics and action readiness of today's captains may be associated with serious challenges. This reflects one of the 'ironies of automation' raised by Bainbridge (1983), cautioning against the creation of workroles that are unchallenging and monotonous, but where the operator nevertheless has to shoulder a great responsibility in case of an accident. It has also been pointed out that ship automation technologies will be associated with new failure patterns (Jalonen et al., 2017; Reddy et al., 2019). Future evacuation hazards will not be limited to those known today, and identifying some types of hazards, such as those arising from the interaction between humans and automation, require deep investigation. Providing equal or better operational performance in automated passenger ferry traffic will demand a sociotechnical approach including human-centered design of technical artefacts, effective work organizations, and measures to build experience and adaptability among the next generation of operators, both at sea and on land.

4.2. Passenger action & independence

In the automation concepts reviewed during this work, different manning solutions are envisaged depending on operational circumstances (e.g. distance to shore), but a common pattern among survey responses is that passengers generally prefer a host to be available on board, both for safety and security reasons (Goerlandt and Pulsifer, 2022; Mehta et al., 2021; Pantelatos et al., 2023). It has previously been mentioned that mustering and evacuating during an emergency can be a difficult process, likely demanding the presence of a trained professional (Pobitzer et al., 2022). In addition, while a situation demanding the eventual evacuation of the ship may take some time to evolve, other situations, such as "man over board", demand a very swift response. The data obtained in this study supports these prior findings. Deckhands described several activities where they may either need to assist passengers (e.g. informing them, assisting their movements, helping out with life vests or facilitating the use of life saving appliances (LSA), or where they may need passengers to assist them (e.g. for heavy lifts or for keeping order). Judging whom among the passengers might be suitable to ask for assistance seems to demand an assessment of character, based on personal interaction. On a ship with no onboard crew, two apparent challenges are to maintain the passenger's trust and to provide effective guidance for their actions, in ways that also encourage positive social behaviors, such as helpfulness and (well-grounded) passenger initiatives.

Several authors have pointed out that the conditions present during an ship emergency may be extremely challenging for some passengers (Jørgensen and May 2002; Sarvari et al., 2019) and that a large variety in passenger characteristics must be taken into account when designing vessels and their equipment (Borgen et al., 2022; Burgén et al., 2023; Goerlandt and Pulsifer, 2022). It is not unthinkable that automation and emergency equipment solutions that either do not function for all, or that do not instill sufficient trust, may steer certain passenger groups away from seaborne travel. While solutions like emergency push buttons are mentioned in the literature (Amro et al., 2020; Thieme et al., 2019) and some suggestions have been made around suitable safety information (Johnsen et al., 2022), there is a need for more detailed studies of passenger-shore interaction, and what communication solutions may satisfy both psychological (e.g. trust) and functional (e.g. incitement and performance of required actions) goals in an emergency, acknowledging the diverse needs of a heterogeneous passenger population. A relevant remark made by a workshop participant in the present study is that the guidance of passengers is not only a matter of facilitating the right action. It can also be a matter of avoiding harmful decisions, such as boarding life saving vessels under dangerous conditions. Creating solutions for both communication and practical evacuation that provide enough simplicity, robustness and flexibility, given the many variables that may affect an individual emergency, is a challenge for the industry.

4.3. Maintaining and improving rescue network performance

The question of the captain's abilities and situation awareness once again becomes relevant when looking at the overall network of organizations that may become involved in emergency response. Interviewees from rescue organizations state that having access to a trained professional at the scene – primarily the captain – is key when it comes to planning and executing the response. Even today, one interviewee said, conflicting interpretations between the Joint Recue Co-ordination center (JRCC) and people at the scene may result in confusion and faulty priorities. Suggestions have been made in the literature around new information resources for rescue operators, for example, giving them access to sensor data communicating the type of accident, the status of safety systems, propulsion and passengers (Pobitzer et al., 2022). First, however, the results of this study suggest that certain data types (passenger information in particular) may be very difficult to obtain, in particular for ferry crossings where passengers remain in their vehicles. Second, it may be questioned whether such raw data has the same worth as a basis for decisions as the professional judgment of, and feedback from, a captain standing on the bridge. Reducing the onboard crew and introducing new roles such as remote operators will change the dynamics of the emergency response network. The interaction between rescue organizations and new actors in this network, such as ROCs, needs to be examined to determine whether these changes in resources and communication patterns affects emergency response capabilities, e.g., in terms of response time.

Our results indicate that removing the captain, or altering the role significantly, may put more pressure on the remaining crew (e.g., a safety host), and that a safety host may also have a different competence profile than today's deckhands. It will be important to study how passengers react to an emergency situation where no onboard command is present. For example, a large amount of distress calls coming from many passengers at once may be a hindrance to the decision-making processes of rescue organizations. Accidents leading to evacuation are quite rare in the operational environment observed in this study. However, an envisioned consequence of having less information (and information of lower quality) regarding an incident, could create a lowered threshold for emergency response, putting more strain on the JRCC and other resources in the rescue network. Such a situation could result in more false alarms, tying up rescue resources that may suddenly be needed for other interventions. In addition, responding organizations arriving at the scene may also have to deal with the consequences of erroneous passenger initiatives (e.g., people in life rafts or in the water).

A final aspect of the larger emergency response network is the reliance on nearby traffic mentioned by several captains in the present study. These local networks appear to depend on personal relations and were mentioned as an important resource in case of accidents, e.g., for the possibility of quickly moving passengers to another ship. Traffic situations where traditional and autonomous ships operate in the same waters are likely in a near future (Kim et al., 2022). Previous research suggests that ships with reduced crews may have smaller chances of aiding other ships (Jalonen et al., 2017), for example, picking up survivors from the water (Wróbel et al., 2017). This is an area that demands more inquiry. First, emergency interaction in mixed-traffic networks needs to be examined, e.g. the communication between traditional ships and ROCs that may or may not be able to control their ships remotely. Second, there is a need for research on technical capabilities ensuring the possibility of mutual aid. For example, interviewees in the present study mentioned that rescue vessels may have trouble docking to a ship in distress, even if there is a captain who can aid the process, which is an issue that has also been stressed in previous research on autonomous passenger ferries (Johnsen et al., 2022; Pobitzer et al., 2022). The possibility of docking safely should also be ensured for non-rescue ships assisting during an accident.

4.4. Conclusions

Studying near-costal passenger ferry evacuation from a sociotechnical perspective reveals a process full of interactions between many different functions and capabilities. In the case of evacuation, the crews manning these ships are tasked with external communication, passenger communication, preparation for evacuation, assisting passengers, and a constant re-assessment of the situation. To complete these tasks, crews rely on their experience and training, simple and usable evacuation technologies, and well-functioning collaboration in a network of various rescue operators. The study shows that the rescue network does not only consist of the different rescue organizations – JRCC, SRSS and the local rescue services – but that the local network of other ships from the same shipping company, or other ships operating in the area, may also fulfill important functions in an emergency.

Bringing automation into any safety-critical system requires a profound understanding of its potential safety benefits, as well as any new hazards it may introduce. This study has shown that the human operators involved in current operations contribute strongly both to safety and operational readiness, and any automation should be introduced with the intent to augment or preserve these capabilities.

This study shows that further research is needed to ensure safety in terms of remote operation situation awareness (including interfaces for supervision and control), remote operator and onboard safety host competencies, passenger safety information and communication, simple and robust evacuation equipment, technical means allowing assistance between autonomous and regular ships, and lastly, both procedures and interfaces for collaboration in a changing rescue network.

CRediT authorship contribution statement

Julia Burgén: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Staffan Bram:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Ahola, M., Murto, P., Kujala, P., Pitkänen, J., 2014. Perceiving safety in passenger ships – User studies in an authentic environment. Saf. Sci. 70, 222–232. https://doi.org/10.1016/j.ssci.2014.05.017.

Ahvenjärvi, S., 2016. The human element and autonomous ships. TransNav Int. J. Marine Navig. Safety Sea Transp. 10 (3), 517–521. https://doi.org/10.12716/1001.10.03.18.

Amro, A., Gkioulos, V., & Katsikas, S. (2020). *Connect and Protect: Requirements for Maritime Autonomous Surface Ship in Urban Passenger Transportation* (S. Katsikas, F. Cuppens, N. Cuppens, C. Lambrinoudakis, C. Kalloniatis, J. Mylopoulos, A. Antón, S. Gritzalis, F. Pallas, J. Pohle, A. Sasse, W. Meng, S. Furnell, & J. Garcia-Alfaro, Eds.). Springer International Publishing. https://doi.org/10.1007/978-3-030-42048-2_5.

Bainbridge, L., 1983. Ironies of automation. Automatica 19 (6), 775–779. https://doi.org/10.1016/0005-1098(83)90046-8.

Borgen, H., Holte, E.A., Gribkovskaia, V., Pobitzer, A., 2022. Smartere Transport Møre og Romsdal L2.1 Fartøyskonsept for Autonom Passasjertransport.

Brekke, E.F., Eide, E., Eriksen, B.-O.H., Wilthil, E.F., Breivik, M., Skjellaug, E., Helgesen, Ø.K., Lekkas, A.M., Martinsen, A.B., Thyri, E.H., Torben, T., Veitch, E., Alsos, O.A., Johansen, T.A., 2022. milliAmpere: an Autonomous Ferry Prototype. J. Phys. Conf. Ser. (2311) https://doi.org/10.1088/1742-6596/2311/1/012029.

Burgén, J., Bram, S., Dederichs, A.S., & Hedvall, P.-O. (2023). No one left behind: a universal design analysis of ship evacuation. *Manuscript submitted for publication*.

Danish Maritime, Authority., 2017. Analysis of Regulatory Barriers to the Use of Autonomous Ships.

Dekker, S.W.A., Woods, D.D., 2002. MABA-MABA or abracadabra? Progress on human–automation co-ordination. Cogn. Technol. Work 4, 210–244. https://doi.org/10.1007/s101110200022.

DNV-GL, 2018. Remote-controlled and Ships in the Maritime Industry [Position Paper]. https://www.dnv.com/maritime/autonomous-remotely-operated-ships/index.html.

European Union, 2020. EU Operational Guidelines For Trials of Maritime Autonomous Surface Ships (MASS). https://transport.ec.europa.eu/system/files/2020-11/guidelines_for_safe_mass.pdf.

Finferries, 2018. Finferries' Falco world's First Fully Autonomous Ferry. Retrieved Oct 11, 2023 from. https://www.finferries.fi/en/news/press-releases/finferries-falco-worlds-first-fully-autonomous-ferry.html.

Fjørtoft, K.E., Rødseth, Ø.J., 2020. Using the operational envelope to make autonomous ships safer. In: Proceedings of 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference. Venice, IT. https://www.sintef.no/globalassets/project/hfc/sarepta/fjortoft-rodseth-2020-using-the-operational-envelope-to-make-autonomous-ships-safer.pdf.

Gauthier, M., Kruithof, G., Narlis, C., Jolliffe, W.A.M., 2019. Control and automation systems onboard the vessel: lessons in human-centered design learned from 20 years of marine occurrences in Canada. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63, pp. 1000–1004. https://doi.org/10.1177/1071181319631066.

Goerlandt, F., Pulsifer, K., 2022. An exploratory investigation of public perceptions towards autonomous urban ferries. Saf. Sci. 145 https://doi.org/10.1016/j.ssci.2021.105496.

Haugan, I., 2022. NTNU Trials World's First Urban Autonomous Passenger Ferry. Sep 22 2022. Norwegian SciTech News. https://norwegianscitechnews.com/2022/09/ntnu-trials-worlds-first-urban-autonomous-passenger-ferry/.

Hollnagel, E., 2012. Task Analysis: why, What and How. In: Salvendy, G. (Ed.), Handbook of Human Factors and Ergonomics, 4th Edition. John Wiley & Sons.

Hollnagel, E., 2021. The Changing Nature of Task Analysis. In: Salvendy, G., Karwowski, W. (Eds.), Handbook of Human Factors and Ergonomics, 5th Edition. John Wiley & Sons.

Hollnagel, E., Woods, D.D., 2005. Joint Cognitive Systems: Foundations of Cognitive Systems Engineering. CRC Press.

International Maritime Organization, 1974. International convention for the safety of life at sea, 1974, as amended by res. MSC 153 (78) on 2004-05-20, Chapter V, Regulation 33: Distress situations: Obligations and procedures (Applicable from 2006 to 07-01).

International Maritime Organization, 1998. International Convention on Maritime Search and Rescue.

International Maritime Organization, 2019. MSC.1/Circ.1604 Interim guidelines For MASS Trials.

International Maritime Organization, 2021. MSC.1/Circ.1638 Outcome of the Regulatory Scoping Exercise For the Use of Maritime Autonomous Surface Ships (MASS).

International Maritime Organization, 2022. MSC 105/7 DEVELOPMENT OF A GOAL-BASED INSTRUMENT FOR MARITIME AUTONOMOUS SURFACE SHIPS (MASS) - Draft road Map For Maritime Autonomous Surface Ships.

Jalonen, R., Tuominen, R., Wahlström, M., 2017. Safety of Unmanned Ships. Aalto University publication series SCIENCE + TECHNOLOGY. http://urn.fi/URN:ISBN:978-952-60-7480-1.

Jansson, E., Olsson, N.O.E., Fröidh, O., 2023. Challenges of replacing train drivers in driverless and unattended railway mainline systems—A Swedish case study on delay logs descriptions. Transp. Res. Interdiscip. Perspect. 21 https://doi.org/10.1016/j.trip.2023.100875.

Johnsen, S.O., Thieme, C., Myklebust, T., Holte, E., Fjørtoft, K., Jan Rødseth, Ø., 2022. Hazards and risks of automated passenger ferry operations in Norway. In: Proceedings of Human Factors in Robots, Drones and Unmanned Systems. https://doi.org/10.54941/ahfe1002312.

Jørgensen, H.D., May, M., 2002. Human factors management of ship evacuation. In: Proceedings of Human Factors in Ship Design & Operation II. London.

Kari, R., Steinert, M., 2021. Human factor issues in remote ship operations: lesson learned by studying different domains. J. Mar. Sci. Eng. 9 (4) https://doi.org/10.3390/jmse9040385.

Karvonen, H., Aaltonen, I., Wahlström, M., Salo, L., Savioja, P., Norros, L., 2010. Unraveling metro train driver's work: challenges in automation concept. In: Proceedings of ECCE 2010 Conference. Delft, NL, pp. 233–240. https://dl.acm.org/doi/10.1145/1962300.1962349.

Kim, T.-e., Perera, L.P., Sollid, M.-P., Batalden, B.-M., Sydnes, A.K., 2022. Safety challenges related to autonomous ships in mixed navigational environments. WMU J. Marit. Affairs 21 (2), 141–159. https://doi.org/10.1007/s13437-022-00277-z.

Lundh, M., Lützhöft, M., Rydstedt, L., Dahlman, J., 2010. Evacuation in practice –observations from five full scale exercises. WMU J. Marit. Affairs 9 (2), 137–151. https://doi.org/10.1007/BF03195171.

Madsen, A.N., Aarset, M.V., Alsos, O.A., 2022. Safe and efficient maneuvering of a maritime autonomous surface ship (MASS) during encounters at sea: a novel approach. Marit. Transp. Res. 3 https://doi.org/10.1016/j.martra.2022.100077.

Mehta, R., Winter, S.R., Rice, S., Edwards, M., 2021. Are passengers willing to ride on autonomous cruise-ships? Marit. Transp. Res. 2 https://doi.org/10.1016/j.martra.2021.100014.

Merriam, S.B., Tisdell, E.J., 2015. Qualitative Research: A Guide to Design and Implementation. John Wiley & Sons, Incorporated.

Nevalainen, J., Ahola, M.K., Kujala, P., 2015. Modeling passenger ship evacuation from passenger perspective. In: Proceedings of Marine Design. London, UK.

Orfanou, F., Vlahogianni, E., Yannis, G., 2021. A taxonomy of skills and knowledge for efficient autonomous vehicle operation. In: Proceedings of Advances in Mobility-as-a-Service Systems, pp. 305–315.

Ostrom, L.T., Wilhelmsen, C.A., 2019. Risk Assessment: Tools, Techniques, and Their Applications, 2nd Edition. John Wiley & Sons.

Pantelatos, L.S., Saghafian, M., Alsos, O.A., St Clair, A.L., Smogeli, Ø, 2023. The Role of a Human Host Onboard of Urban Autonomous Passenger Ferries. International Academy Research and Industry Association (IARIA). https://hdl.handle.net/11250/3083722.

Pobitzer, A., Sadjina, S., Holte, E.A., 2022. Smartere Transport Møre & Romsdal – L2.4/L3.2 – Sikker dokking, ombordstigning, Evakuering Og Krav Til Landside. https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3085924.

Rausand, M., Haugen, S., 2020. Task Analysis Techniques. In: Ostrom, L.T., Wilhelmsen, C.A. (Eds.), Risk Assessment: Theory, Methods, and Applications, 2nd edition. John Wiley & Sons.

Reddy, N.P., Zadeh, M.K., Thieme, C.A., Skjetne, R., Sorensen, A.J., Aanondsen, S.A., Breivik, M., Eide, E., 2019. Zero-emission autonomous ferries for urban water transport: cheaper, cleaner alternative to bridges and manned vessels. IEEE Electrif. Mag. 7 (4), 32–45. https://doi.org/10.1109/mele.2019.2943954.

Roboat, 2022. Roboat. Retrieved Oct 11, 2023 from. https://roboat.org/.

Rødseth, Ø.J., Burmeister, H.-C., 2015. Risk assessment for an unmanned merchant ship. TransNav Int J.Marine Navig. Safety Sea Transp. 9 (3), 357–364. https://doi.org/10.12716/1001.09.03.08.

Salmon, P., Jenkins, D., Stanton, N., Walker, G., 2010. Hierarchical task analysis vs. cognitive work analysis: comparison of theory, methodology and contribution to system design. Theor. Issues. Ergon. Sci. 11 (6), 504–531. https://doi.org/10.1080/14639220903165169.

Salonen, A.O., 2018. Passenger's subjective traffic safety, in-vehicle security and emergency management in the driverless shuttle bus in Finland. Transp. Policy. (Oxf) 61, 106–110. https://doi.org/10.1016/j.tranpol.2017.10.011.

Sarvari, P.A., Cevikcan, E., Celik, M., Ustundag, A., Ervural, B., 2019. A maritime safety on-board decision support system to enhance emergency evacuation on ferryboats. Marit. Policy Manage. 46 (4), 410–435. https://doi.org/10.1080/03088839.2019.1571644.

Stanton, N.A., 2006. Hierarchical task analysis: developments, applications, and extensions. Appl. Ergon. 37 (1), 55–79. https://doi.org/10.1016/j.apergo.2005.06.003.

Stene, T.M., 2018. Automation of the rail—removing the human factor? Safety and Reliability - Safe Societies in a Changing World, 1st Edition ed. CRC Press. https://www.taylorfrancis.com/chapters/oa-edit/10.1201/9781351174664-244/automation-rail%E2%80%94removing-human-factor-stene.

Storstockholms brandförsvar, 2021. Storstockholms Brandförsvars övergripande styrdokument - Inklusive handlingsprogram Enligt LSO 3 kap. 3 Och 8 §§ För år 2022-2023. https://www.storstockholm.brand.se/globalassets/dokument/styrdokument-och-rapporter/2022/ssbf-overgripande-styrdokument-inkl.-hp-2022-2023_mr.pdf.

Strauch, B., 2018. Ironies of automation: still unresolved after all these years. IEEe Trans. Hum. Mach. Syst. 48 (5), 419–433. https://doi.org/10.1109/thms.2017.2732506.

Swedish Accident Investigation Authority, 2023. Final report SHK 2023: 01e, Fire on the vessel ALMIRANTE STORNI in December 2021, off Gothenburg.

Lag om skydd mot olyckor, 2003:778. Svensk Svensk författningssamling (SFS). https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-2003778-om-skydd-mot-olyckor_sfs-2003-778#K3.

Sjölag, 1994:1009. Svensk Svensk författningssamling (SFS). https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/sjolag-19941009_sfs-1994-1009/#K17.

Swedish Maritime Administration, 2021a. Collaboration and Administration. Retrieved Feb 29, 2024 from. https://www.sjofartsverket.se/en/search-and-rescue/collaboration-and-administration/.

Swedish Maritime Administration, 2021b. Search and Rescue. Retrieved Nov 8, 2023 from. https://www.sjofartsverket.se/en/search-and-rescue/search-and-rescue/.
Swedish Maritime Administration, 2022. Svenskt Program För Sjö Och Flygräddningstjänst. https://www.sjofartsverket.se/contentassets/14b02cd8257d444c87e191ede0e13e8d/svenskt-program-for-sjo–och-flygraddningstjanst-2022.pdf.
Swedish Coast Guard, n.d. Rescue Service. Retrieved Nov 8, 2023 from https://www.kustbevakningen.se/en/mission/rescue-service/.
Swedish Maritime Administration, 2023. n.d. *SAR Co-operation plan.* Retrieved 8.
Swedish Sea Rescue Society, n.d. *Information in English*. Retrieved Nov 8, 2023 from https://www.sjoraddning.se/information-english.
Swedish Transport Agency, 2019. Smarta Fartyg – En självkörande Sjöfartsmarknad Utan hinder? https://www.transportstyrelsen.se/globalassets/global/publikationer-och-rapporter/sjofart/rapport-191030.pdf.
Thieme, C.A., Guo, C., Utne, I.B., Haugen, S., 2019. Preliminary hazard analysis of a small harbor passenger ferry – results, challenges and further work. In: Journal of Physics: Conf. Series, 1357. https://doi.org/10.1088/1742-6596/1357/1/012024.
Thieme, C.A., Ramos, M.A., Holte, E.A., Johnsen, S.O., Myklebust, T., Smogeli, Ø., 2023. New design solutions and procedures for ensuring meaningful human control and interaction with autonomy: automated ferries in profile. Autonomous Vessels in Maritime Affairs, pp. 213–242. https://doi.org/10.1007/978-3-031-24740-8_11.
United Nations, 2006. Convention On the Rights of Persons with Disabilities. https://social.desa.un.org/issues/disability/crpd/convention-on-the-rights-of-persons-with-disabilities-crpd.
van de Merwe, K., Mallam, S., Nazir, S., Engelhardtsen, Ø., 2024. Supporting human supervision in autonomous collision avoidance through agent transparency. Saf. Sci. 169 https://doi.org/10.1016/j.ssci.2023.106329.
Vassalos, D., Christiansen, G., Kim, H.S., Bole, M., Majumder, J., 2008. Evacuability of Passenger Ships At Sea.
Veitch, E., Alsos, O.A., 2022. A systematic review of human-AI interaction in autonomous ship systems. Saf. Sci. 152 https://doi.org/10.1016/j.ssci.2022.105778.
Venverloo, T., Duarte, F., Benson, T., Bitran, Q., Beldad, A.D., Alvarez, R., Ratti, C., 2020. Evaluating the human experience of autonomous boats with immersive virtual reality. J. Urban. Technol. 28 (3–4), 141–154. https://doi.org/10.1080/10630732.2020.1802214.
Wahlström, M., Hakulinen, J., Karvonen, H., Lindborg, I., 2015. Human factors challenges in unmanned ship operations – insights from other domains. Procedia Manuf. 3, 1038–1045. https://doi.org/10.1016/j.promfg.2015.07.167.
Wang, S., Zhang, Y., Wang, X., Huo, R., Song, F., Zhai, P., 2022. A novel maritime autonomous navigation system: from design to real ship trial. In: Proceedings of 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), pp. 1362–1366. https://doi.org/10.1109/ITSC55140.2022.9921769.
Wang, X., Liu, Z., Zhao, Z., Wang, J., Loughney, S., Wang, H., 2020. Passengers' likely behaviour based on demographic difference during an emergency evacuation in a Ro-Ro passenger ship. Saf. Sci. 129 https://doi.org/10.1016/j.ssci.2020.104803.
Wróbel, K., Montewka, J., Kujala, P., 2017. Towards the assessment of potential impact of unmanned vessels on maritime transportation safety. Reliab. Eng. Syst. Saf. 165, 155–169. https://doi.org/10.1016/j.ress.2017.03.029.
Zeam, 2023. Zeam - Making urban Life Flow. Retrieved Oct 11, 2023 from. https://www.zeam.se/.
Zhou, H., Ren, Z., Marley, M., Skjetne, R., 2022. A guidance and maneuvering control system design with anti-collision using stream functions with vortex flows for autonomous marine vessels. IEEE Trans. Control Syst. Technol. 30 (6), 2630–2645. https://doi.org/10.1109/tcst.2022.3161844.