From captain to button-presser: operators' perspectives on navigating highly automated ferries

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Abstract. Teaming with Artificial Intelligence (AI) is changing the way seafarers work. We show that a new kind of seafaring is emerging, characterized by cooperation with AI systems. In this format of seafaring, navigation tasks are controlled automatically while human operators manage the automation, always "in the loop" and ready to take over control if necessary. Ideally, this arrangement sees improvements in overall system performance and safety. However, little is known today about how this format of work will unfold in real-world operations. We investigate this topic by interviewing operators (n = 5) on ferries recently outfitted with state-of-the-art automated navigation technology. We used a mixed-methods approach to analyze the case study interviews, combining quantitative text analysis with Grounded Theory qualitative analysis techniques. The results show that operators perceived a shift towards a backup role coincident with increasing agency of machine autonomy. This role shift was characterized by "button-pressing" to start the machine autonomy and subsequently intervening to stop it when things go wrong. We observed that this shift led to boredom, de-skilling, stretched resources, and compromised organizational harmony – effects running counter to the intention of improved system performance and safety. Synthesizing the findings, we present (1) effects across three operational dimensions: (i) tasks, (ii) human-computer interaction, (iii) organization; and (2) a definition of collaborative (human-AI) seafaring. By identifying issues in the early implementation of highly automated ship navigation, we hope to guide designers of Maritime Autonomous Surface Ships (MASSs) away from potential pitfalls and towards development more in tune with real-world demands of collaborative work.

1. Introduction

The work of seafarers is changing with the development of increasingly intelligent machines used for ship navigation. Meanwhile, Maritime Autonomous Surface Ships (MASS), are evolving from concept designs to real-world implementation, representing the next major shift in seafaring work. MASSs, despite containing high levels of machine autonomy, still require human supervision and remote intervention when things go wrong. Currently, little is known about how this format of seafaring will take place. One approach to addressing this knowledge gap is by examining current changes in how seafaring work is changing aboard highly automated ferries. While not MASS per say, highly automated ferries share similar features. This includes the following precepts for cooperation with the automation: (i) the operators can turn on and off the automation, (ii) the operator must intervene to take preventative actions, and (iii) sufficient situation awareness is needed to "get in the loop" for that preventative action to be appropriately executed. Like MASSs, current highly automated ships also share waterways with predominantly manned vessels, resulting in subtle shifts in expectations for communication and collision avoidance. Developers of MASS have for almost a decade outlined the need for a Shore Control Center, where operators can manage MASS fleets, always "in the loop" and ready to intervene. In this vision, the benefits of machine autonomy are enabled by close cooperation with skilled human operators.

Cooperation with automation is far from straightforward, however. Human factors experts have catalogued a multitude of complications arising from work with intelligent machines, foremost of which is the effects automation can have on their ability to pay attention. Explanations of how operator performance is affected by automation, while still not universally accepted, range from theories of situation awareness [1] to vigilance [2] and mental workload [3]. Yet, experts are unanimous in their agreement that increased automation, if not designed correctly, leads to mental underload among operators – a state of boredom that is potentially hazardous if one's work involves swiftly taking over control to avoid disaster. Dramatic examples have already been reported from highly automated cars. In two separate National Transportation Safety Board (NTSB) reports, overreliance on Tesla's *AutoPilot* system led to fatal accidents when the inattentive driver was unprepared to take over control [4,5]. This led to recommendations directed towards technology companies that included "minimizing driver disengagement, preventing automation complacency, and accounting for foreseeable misuse of the automation" [6]. Looking ahead at MASS operators, the line blurs between seafarer, technologist, and level-headed emergency responder – a new breed of ship operator whose lofty skill requirements may exclude just about any applicant [7].

Seafarers themselves are ambivalent about the development of MASS. Recent studies that have surveyed seafarers show that, while open to technology change, they believe operation of autonomous ships will require significant changes to the skills and competences currently at the core of standardized seafaring curricula [8,9]. Others have reported specific concerns on the part of seafarers contending with automation, which included sensor over-reliance, compromised situational awareness, and increased complacency (while paradoxically providing little reduction in fatigue levels) [10]. The history of ship navigation has drawn a parallel arc to that of modern technology development, punctuated by the advent of tools like the sextant, compass, radio, radar, electronic charts, and Dynamic Positioning (DP). There is a long precedent in academic interest on this topic, both in the context of automation [11] and in the context of collaborative work [12]. Recent advances in Artificial Intelligence (AI), however, challenge current paradigms of technology interaction. Machines capable of completing tasks on their own largely supersede the manual interaction traditionally associated with navigation tools. A sextant cannot locate a star by itself, nor can a DP system hold station without the fine-tuning of an operator. An autonomous ship can, by contrast, sail from port to port by itself, avoiding collisions and even optimizing fuel consumption along the way. John McCarthy, who is credited with coining the term "Artificial Intelligence," defined intelligence as the "computational part of achieving goals in the word" [13]. While this definition is not universally accepted, we adopt it here by virtue of its simplicity. By this definition, the auto-crossing and auto-docking systems that we feature in our case study can be considered AI systems, even if they currently function with rule-based algorithms. Although, if current research trends are any indication, we can expect to see more sub-symbolic techniques commonly associated with contemporary AI applied to future ship navigation (e.g., [14]).

A milestone in autonomous ship development came in 2018 when the International Maritime Organization (IMO) first formally acknowledged MASSs [15]. At that time, it was announced that a scoping exercise would get underway aiming to highlight where MASSs fell outside of existing regulations. The results of the scoping exercise listed “high-priority issues,” of which the top three items related to the operator whose assumed role it was to supervise control of the MASSs [16]. Fundamental questions were raised, not least of which questioned the meaning of master, crew, and responsible person in such a system. Around the same time, Stanford University published its influential *AI100 Report*, summarizing state-of-the-art technology and research [17]. “Perhaps the most inspiring challenge,” they wrote, “is to build machines that can cooperate and collaborate seamlessly with humans’ (p. 19). If the early optimism surrounding intelligent machines was inspired by a technology-driven approach to computational systems, recent thinking elevates human presence and the question of how best to extend attributes of collaborative work to these intelligent machines.

Our case study examines auto-crossing and auto-docking, two recent technologies implemented on Norwegian coastal ferries [18]. The functionality is straightforward (see Figure 1), with one panel containing a series of four buttons: Auto-cross, Manual, Auto-dock, and Autopilot. A typical ferry crossing starts by pressing “Auto-dock,” which takes the ferry from dock. “Auto-cross” then initiates an automated crossing by following pre-set waypoints, whereupon “auto-dock” is pressed again upon approaching the arrival dock. Currently, auto-crossing does not detect nor avoid other objects. “Manual” is for taking over control and “Autopilot” is for conventional autopilot. A tablet-sized screen relates system information like the thrusters’ power and orientation. For simplicity, we refer to auto-crossing and auto-docking collectively as the “auto-systems.” The motivation for interviewing operators of these auto-systems was inspired by the need for “nitty gritty” detail about operators’ experiences working with increasingly intelligent systems on ships. Much of the literature is dedicated to the development side, ranging from conceptual frameworks and methodologies to descriptions of new techniques and prototypes. An important question remained unanswered, one that formulates our research question: how does AI technology used to navigate ships affect real-world seafaring work? We set out to design a case study that would shed light on this question. Our aim was to provide more than just an expository account of operators’ begrudging views on technology. Rather, it was to describe a phenomenon of growing relevance for MASS operations, and to identify pitfalls on the path from concept design to real-world implementation.

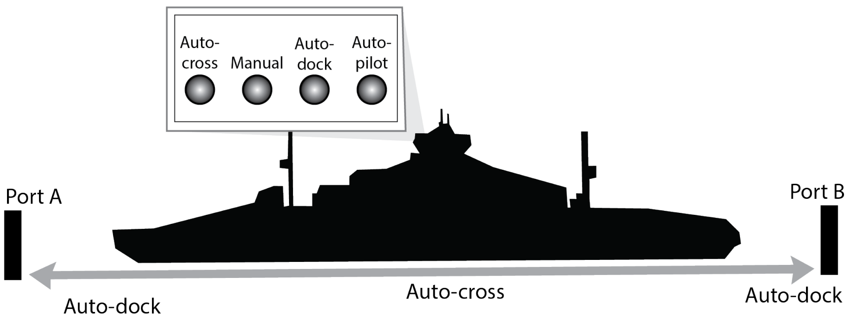

Figure 1*:* Illustration showing a Ro-Ro ferry with auto-crossing and auto-docking.

2. Method

We interviewed captains and chief mates (n = 5) who worked aboard two Roll-On Roll-Off (Ro-Ro) ferries using state-of-the-art automated navigation technologies. One of these ferries, the MF *Korsvika*, was equipped with both auto-crossing and auto-docking. The other ferry, the MF *Vikhammer*, was instrumented with just auto-crossing. Both ferry names are pseudonyms to protect anonymity of the interviewees. The interviews were conducted by the first and second authors in June 2021 and translated from the Norwegian with the help of an expert in marine terminology. Table 1 presents information about the two ferries and the operators’ experience levels using the automation technology. The interviews were semi-structured, focused around four main questions: (i) Can you tell us about your background and experience? (ii) Do you have a name you use for the new automated navigation systems? (iii) What changed, if anything, since this technology was introduced? (iv) Have you become a better navigator as a result of the automation? Informed consent was obtained for all interviewees. All interviews were transcribed verbatim.

Table 1. Characteristics of the two Ro-Ro ferries and their operators we interviewed.

		
Ferry[a]	MF *Korsvika*	MF *Vikhammer*
Length overall	Approx. 140 m	Approx. 105 m
Capacity	Approx. 600 pax; 200 cars	Approx. 350 pax; 120 cars
Crossing length	Approx. 6 nm; highly trafficked	Approx. 1 nm; sparsely trafficked
Operators[b]	**Ola, Lars & Robin**	**Henrik & Magnus**
Auto-crossing	1-2 years' experience	1-2.5 years' experience
Auto-docking	1-2 years' experience	N/A
Avg. experience	26 years	9 years

[a] Names of ferries are pseudonyms.
[b] Names of operators are pseudonyms. Operators held D1 certificates: the highest navigation license in Norway, which reserves the title of "captain."

2.1. *Mixed-methods approach*
We combined qualitative case study analysis and quantitative analysis techniques in what is referred to as a "mixed-methods" approach [19]. We describe the two methods below.

2.1.1. Quantitative analysis. The quantitative approach leveraged the text analysis software Leximancer [20] to identify salient themes, patterns, and relationships in the interview transcripts [21,22]. Leximancer executed a content analysis, where "coding" (i.e., highlighting relevant parts of text) is automated using latent semantic analysis indexing [23]. This resulted in a network of related emergent concepts, as depicted in Figure 2. The interview transcripts were pre-processed into a format that distinguished speakers and their respective ferries. The analysis excluded content from the interviewer. The "concept map" in Figure 2 was generated from linked concepts (words) and thematic clusters (circles). The clusters represented analytical insights, as they were based on patterns and relationships in the interview data. Several interview excerpts were supplied for each theme, providing a rationale for the clustering. In Figure 2 we labelled each cluster with a theme label, each of which we describe in the Findings.

2.1.2. Qualitative analysis. In addition to the quantitative text analysis, a qualitative approach was adopted based on Grounded Theory in the tradition of Glaser & Strauss [24] and Morse [25]. Grounded Theory techniques allow researchers to minimize bias in theory development by virtue of the techniques' transparent grounding in observations. One useful technique we adopted was that of "memos," described by Corbin & Strauss [26] and Glaser & Strauss [24]. In memos, descriptions of thoughts and impressions are immediately written down upon first interaction with the data. In the end, we had 101 such memos, ranging from short notes to descriptive passages. Memos served two practical purposes: (i) they provided a record of early insights at a critical time when the researcher's mind was free from the "pull" of early explanations, and (ii) it served to gauge the extent to which our sampling had reached saturation. Since we sampled as we went along in the analysis (so-called "theoretical sampling"), we reached a sampling saturation when the memos revealed enough findings that we considered it not worthwhile to interview more operators. From the early insights gained in the memos, we proceeded to code the transcripts in the text analysis software NVivo [27] and subsequently aggregate concepts into an overarching narrative structure.

Our aim was to describe a phenomenon that applied in equal measure to the population of ship navigators as to the sampled individuals. Here converging evidence (or "triangulation") played an important role. The data were independently analyzed in the context of our research question, whereupon results were compared and iteratively discussed prior to collating them in the Findings. Triangulation was accomplished across three groups: (i) the first and third authors (qualitative case study analysis) and (ii) the second author (quantitative analysis), and (iii) fourth, fifth, and sixth authors (qualitative analysis on the *Korsvika* subset of the data).

3. Findings

In this section, we present the results of the mixed-methods analysis, identifying and describing effects of AI technology on seafaring work. The quantitative analysis is presented first, before continuing with the qualitative analysis. We conclude the section by synthesizing the findings into a table classifying effects into three operational dimensions (Table 2): (i) tasks, (ii) human-computer interaction, and (iii) organization

3.1. Quantitative analysis

The thematic analysis is visualized in the concept map (Figure 2). Presented below are five themes (named by the researchers) along with corresponding excerpts identified by Leximancer as particularly relevant. The themes are ordered from most significant to least significant based on the amount of text associated with it.

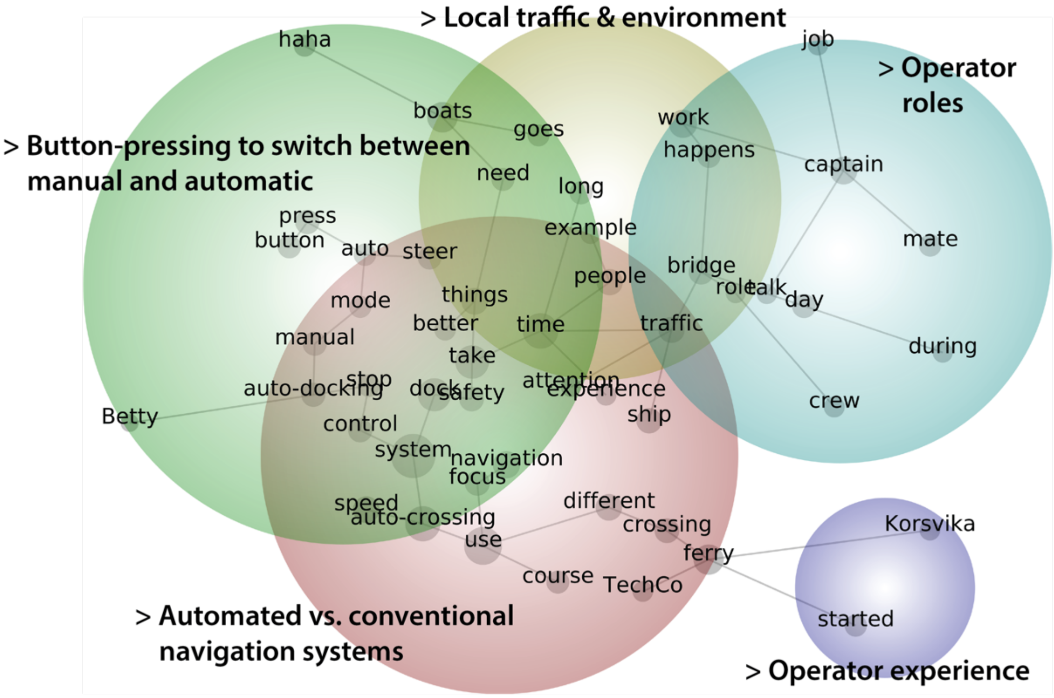

Figure 2*:* Leximancer concept map. The following are pseudonyms: "Betty" (nickname for auto-system), "TechCo" (developer of auto-system), and "Korsvika" (one of the two Ro-Ro ferries).

3.1.1. Automated versus conventional navigation systems. Conventional navigation consoles required the operators to focus on manually maneuvering the ferry. The new systems, by contrast, could do much of the maneuvering automatically, meaning the operators were free to focus their attention elsewhere. They could keep lookout for other vessels using the chart plotter, radar, or simply by looking out the windows. They could also handle unexpected events or catch up on administrative work. The automated systems were even expected to save fuel compared to conventional navigation.

> "We have gotten more technologically demanding systems, which requires a different focus than before in certain areas. Before, you used an old diesel ferry and pushed it into the dock, and no one cared about fuel consumption." – Lars

3.1.2. Local traffic and environment. The operators on *Korsvika* needed to intervene often (up to once per day) with the auto-crossing system because of small boats and other ships in the area. *Vikhammer* sailed mostly as planned, without navigator intervention, due to a scarcity of local marine traffic. This difference is illustrated below, with one quote from each crossing.

> "I check for small boats that [Vessel Traffic Services] doesn't pick up. They miss a few sometimes, so you have to pay attention." – Henrik

> "I'd love to try another crossing with more ship traffic. You still have to keep an eye out, of course, but work on the bridge has changed." – Magnus

3.1.3. Pressing buttons to switch between manual and automatic. This theme was related to the process of switching between automatic and manual modes and what happened if the correct procedure was not followed. The interplay between the operator and the control panel, which consisted of four buttons, featured heavily in the informants' accounts. (This can be seen in Figure 2, where the concepts "button," "press," and "screen" appeared as linked. These were also linked to "haha," indicating informants' laughter, and "Betty," the nickname two of the five informants assigned the auto-system.)

> "When you press it, you see that it's about to auto-dock. But if you don't see it, it beeps again that you have to take over." – Henrik

> "It's been a half year now since fog and all that. But you could just press the button and [auto-docking] went great." – Robin

3.1.4. Operator roles. The operators provided rich details about their roles. The result was a picture of how work typically transpired aboard the two highly automated ferries.

> "On the bridge, the captain and chief mate shift roles throughout the day. Typically, it's two hours on the bridge, two hours for other tasks." – Lars

3.1.5. Operator experience. This theme was about the operators' background experience. Although it was the least significant of the themes, it served to emphasize how much operators valued experience as part of their work.

> "I started as a deck hand [when I was a teenager]." – Ola

3.2. Qualitative analysis

In this section we expand on the five themes above using qualitative analysis techniques, completing the mixed-methods analysis. We dig deeper into the underlying meaning of the emergent themes, uncovering relevant excerpts as supporting evidence. The analysis is presented in three parts: (i) analysis of the auto-systems' agency, (ii) list of three benefits of the auto-systems, and (iii) list of three drawback of the auto-systems.

3.2.1. Agency of the auto-systems. When asked to describe the automated navigation systems in their own words, two of the captains aboard the *Korsvika* explained that they had taken to calling it by a nickname: "Betty" (a pseudonym). Robin explained:

> "My captain and I, if we're auto-docking, we say that 'Betty's taking care of it.' Then he knows that auto mode is on, haha. If we have normal autopilot on, then I say that 'Betty's not taking care of it,' haha."

Ola also calls the auto-systems Betty. This nickname, traditionally a woman's name, is based on the voice announcements of the system, which are recordings of a woman's voice. Ola reveals how this voice makes it easier to assign the system human-like characteristics:

> "…she can nag a bit, haha. The system works well as it is set up, but it needs some fine-tuning because the system does some weird things that people do not do. She has an arrival that's not logical. Those who've made it certainly don't think so, but for us who steer the ship, we steer it better than the system does."

Here Ola refers to the auto-systems by the pronoun "she" which is characterized as doing "weird things." The attribution of human qualities to physical objects is called personification. Personification is a type of metaphor whose power, as described by Lakoff & Johnsen [28], is to allow one to make sense of phenomena in the world in human terms. Personification lends the AI system agency – the ability to actively influence the world. The agency affords the auto-systems its own "elbow room" on the bridge. As we will see in the remaining analysis, this agency underpins both the benefits and drawbacks we observed in human-AI teaming.

3.2.2. Benefit: Attention is freed up. All ferry operators described the freeing effect the auto-systems had on their capacity for attention. As illustrated by Henrik, this was generally perceived as a benefit:

> "… [when I drive] over with auto-crossing, it's just so I can pay attention the traffic. It [driving manually] is one less thing I need to pay attention to. When the ferry comes to a waypoint and is about to turn, it does so. It follows the planned route. We can pay attention and monitor ship traffic more. There's lots of info you need to process there. So, you have one thing less to think about. As soon as something is wrong, you give alerts. When there's nothing wrong, it's good – then it's an assistant." – Henrik

The term "assistant" is a relevant one, because it indicates a hierarchy whereby the operator can override the auto-system. Lars described this phenomenon in similar terms: "If you free up work one place, now you can focus on another." Lars explained that the natural place to re-allocate attention was on navigation duties. "You make one task easier by not having to control speed and energy consumption, but you can't take away attention to the traffic picture."

Small vessels (recreational craft and sailboats) were highlighted as focal points of re-focused attention. Because auto-crossing does not detect nor avoid other objects, the operators were attentive to potential collision scenarios. While larger ships behaved largely as expected, following the "rules of the road" and communicating intentions over radio, small vessels could behave erratically. All *Korsvika* operators interviewed noted an increasing trend in the number of small vessels and remarked on their limited understanding of marine traffic regulations. "The biggest problem is our summer with small boats and sailboats," related Ola. "These boats don't know how to behave at sea." Manual takeover was evidently more likely for smaller vessels and was reported by one *Korsvika* operator to occur as often as once per day during peak summer season.

3.2.3. Benefit: Docking is easier in poor visibility. All three ferry operators aboard the *Korsvika* reported independently that the auto-docking system made docking in poor visibility significantly more effective. “In thick fog, you spend a very long time on radar and [looking for] fog lights,” explained Ola. “In auto you can sit back and let the system do it.” Henrik, taking a pragmatic view of the auto-system’s benefits, claimed that “It’s very nice to use in certain situations... In fog, for example, it’s absolutely fantastic.” Similarly, Robin explained:

> “…the system is ingenious. We see absolutely nothing in the fog… We see it hits the mark just as well as during clear weather… it’s super useful.”

3.2.4. Benefit: Maneuvering is more consistent with less “human errors.” Several operators pointed out that unlike the navigation crew, each of whom possess their own idiosyncratic style of operating, the auto-system does the same thing, every time. Henrik explained:

> “It [the auto-system] is much more stable, in a way. We have eight different navigators [on this ferry], and all of them do their job a little differently. The system always does the same. There are always some variables for us humans that the system does not have.”

Henrik implies that the natural variation among operators is levelled by the auto-system. It also suggests that circumventing “human error” makes maneuvering safer. Lars pitted the operators’ ability to maintain low fuel consumption directly against that of the auto-system: “On single trips, the navigator beats the system. But over time, on average, auto-crossing will beat most navigators. A navigator can't handle 100% focus on [optimal energy use] all the time.

3.2.5. Drawback: Resources can be “stretched.” Although freed-up attention was mostly framed by operators as a benefit, tensions arose when it was re-allocated in a way that stretched their capacities. Magnus illustrated this with a telling example:

> “I think that technology sometimes trumps safety, trumps people on board… I also run a kiosk, selling chocolate and things. They [management] feel that when auto-crossing is there, they can give him [the operator] other tasks.”

Here Magnus reported that following implementation of the auto-crossing system, they are told to periodically leave navigation duties and run the kiosk for passengers during crossing. A latent tension is manifested in the mate’s subtle criticism of “they” (presumably the ship’s management) for re-allocating resources in a way that was perceived as compromising safety. Lars raised a similar concern, stating that “…auto-crossing is more about energy saving than safety.” The benefit of increased efficiency enjoyed by one group (ship management) is cast as the drawback of hazardously stretched resources for another (the operators moonlighting on other tasks).

3.2.6. Drawback: Operators may resent increased automation of their tasks. Friction emerged between operators and developers of the auto-systems when the technology was perceived by the former as part of a misguided endeavour to replace human operators. As Ola explained,

> “The engineers must have something to invent… [and] since they have the shipowners on their side, they make sure that they can get rid of people and hope that the system can be more economical.”

Ola continued, resenting developers’ short-sightedness in assessing technology benefits, while at the same time feeling powerless to stop them:

> “We call it ‘progress’ don’t we, and the world is moving forward and there are a bunch of people from the university involved. They just have to come up with something. Much of our jobs can be automated… I would call this natural progress.”

In a less heavy-handed tone, Robin conveyed a sense that developers did not fully appreciate operators' tacit knowledge for ship maneuvering gained from many years' experience at sea. They related that in some weather conditions, they take over control for the sole reason of making the passage more comfortable for passengers:

> "If it's too windy we run in manual mode. We haven't tested so much in the wind, but these days we say: 'if it's blowing, we steer manually.' I think auto-crossing can be used at any time, but manual mode is more comfortable for passengers… for example if you have rolling, people can fall and hurt themselves. Instead of rolling all the way over, I sail a little North and then a little South to go across the waves."

3.2.7. Drawback: Passivity can lead to boredom and de-skilling. Whereas freed-up attention could be re-allocated in a way that stretched resources beyond their optimal capacities, the opposite was also observed. Attention re-allocated to nothing resulted in boredom. Boredom in the operator's role is clearly dangerous if it leads to inattentiveness and de-skilling over time. The dimension of time, conveyed by words describing past and future, emerged as closely linked to boredom.

> "The working day of the captain will get boring. You press three buttons. There's no challenge. You become an operator who monitors the system and is ready to press a button if there's a bug in the system." – Ola

Here Ola conveys a sense that boredom is a direct threat to ferry operators, whose manual ship maneuvering duties are ceding to automated machines. The sense of safety responsibility also seems undermined, as well as the ebbing away of the high status traditionally with ferry operators. For Magnus, this sentiment is manifested in a desire to transfer to a crossing with more ship traffic, if only to have something to which to pay attention.

> "Now you just press the button and wait for the beep. You become more unfocused on the tasks. You look at the radar occasionally, but here there's no boats. I'd love to try another crossing with more ship traffic. You still have to keep an eye out, of course, but work on the bridge has changed. You get a little unfocused, you know that the computer does the job." – Magnus

In this vein, the topic of land-based control of MASSs emerged, despite never being expressly mentioned by the interviewer:

> "Looking further into the future, I see fewer people. If you eventually sit at the land station and monitor, it'll be a completely different working day." – Henrik

One of the questions we asked was whether operators felt they had become better navigators because of the auto-systems. Surprisingly, no responses came back positive, despite the clear benefits reported. "… No, I wouldn't claim that." responded Ola. "You become complacent. You forget to pay attention. You just leave everything up to the autonomous." Henrik responded to the question similarly: "No, I haven't [become a better navigator], but I'm not any worse either." Magnus answered:

> "No. You become better at understanding technological equipment, but you don't become a better navigator by just sitting there. Okay, the boat goes by itself, so you can have more focus on radar and things like that. But where I am, without ship traffic, you get bored."

Meanwhile, past technologies were occasionally romanticized. Musing on the constant upgrades to navigation technology, whether it be electronic chart display or automated systems, Robin quipped, "It's the oldest stuff that works." Magnus wistfully described his past work, saying, "I experienced a lot of the world with ancient navigation, using astronomy and a bearing compass... Before I started with [my current employer]."

De-skilling was linked to increased passivity. Asked how often Magnus used auto-crossing aboard *Vikhammer*, he responded, “We only use auto-crossing now. Every day, every trip.” Following up by asking if there was ever need for manual takeover, Magnus responded:

> “We might occasionally drive if we have an ambulance dispatched… with an ambulance it’s life and health. Apart from that… it’s been one-and-a-half years since I stopped doing it [driving manually] myself.”

Hearing this, one might ask, is Magnus prepared to “get in the loop” and drive manually in such an emergency? Accounts from operators aboard the *Korsvika*, by contrast, whose operators regularly took over manual control, suggested the answer is likely “No.” Robin elaborated on how manual steering is now regular practice on *Korsvika*, where 50-70% of crossing “go on auto:”

> “We’ve set it up so you’ll sail it yourself during the day to maintain your driving. That’s written in our procedures now. If you’ve had a holiday, you’re allowed to steer the whole shift, there’s no one that says you must use auto-crossing… when I come in on Monday, I usually steer for the first crossing, it’s nice to feel the weather a bit, the conditions on the water.”

Despite the differences between the two vessels, (who have different owners, different automation technology, and sail on crossings with different traffic conditions), all interviewees experienced a fundamental shift in their role as operators. The shift was best described as one towards a “backup” role to the automated navigation system. Or, in the language of the operators (and as indicated in the concept map in Figure 2), the operators were becoming “button-pushers,” arbiters of when to start and stop the automation. As Ola put it, “You only become an operator who monitors the system and is ready to press a button if there’s a bug in the system.”

3.3. Summary

Table 2 contains a synthesis of the findings, where the effects of AI technology on seafaring work have been classified into three dimensions, or “orders.” Starting with the first-order benefits of introducing the auto-systems (“Tasks”), we can proceed to second-order interaction effects (“Human-Computer Interaction”) and finally third-order effects among groups of people (“Organization”).

Table 2. Effects of implementing automated navigation aboard *Korsvika* and *Vikhammer*.

1st-order effect (Tasks): **Efficiency improved**
Immediate benefits: Fuel optimization; Docking made easier in poor visibility; Lower frequency of human errors in control; Higher consistency of operations
2nd-order effect (Human-Computer Interaction): **Attention freed up**
If refocused on too little: Boredom; De-skilling *If refocused optimally: Operator “in-the-loop”* *If refocused on too much: Stretched resources*
3rd-order effect (Organization): **Operators’ shift to “button-pressing” backup role**
Resentment towards developers: Perceived undervaluing of tacit knowledge gained through experience; Undermining captain status *Resentment towards owners:* Safety perceived as compromised when resources are stretched; Foreboding of job automatization

The benefits of the auto-systems appear exclusively as first-order effects in Table 2. The drawbacks emerge later, and with less obvious manifestations. How appropriately the system is implemented hangs in the balance of how newly freed-up attention is re-focused. The shift towards a "button-pressing" backup role resulted in feelings of resentment towards both developers and ferry management, whose short-sightedness in prioritizing first-order benefits they perceived as undermining safety, their most fundamental duty as ferry operator.

4. Discussion

Here we explore how the findings can help advance implementation of machine autonomy. In this aim, we compare our findings with state-of-the-art research, drawing especially from the growing communities of Explainable AI (XAI), machine behaviour, and AI safety.

We begin by acknowledging the need for a working definition for the shifting format of seafaring work marked by collaboration with highly automated navigation technology. Such a definition serves to distill the observations presented in the Findings into a from useful for further discussion and construction of the concept. Below is presented a working definition of the concept of collaborative human-AI seafaring (or "collaborative seafaring" for short).

Collaborative seafaring: a format of seafaring whereby tasks are coordinated between machine agents and human operators in such a way that improves the ability to collaborate with and support seafarers' primary control duties and safety responsibilities.

A key property of agency is that it is definable only in relation to those whose actions are influenced by it. Only recently are we beginning to understand the implications of introducing machine agents into our working lives. In our case study, the has focus of these implications has been on ferry navigation. For MASS in general, progress has been made towards establishing design frameworks laying the foundation for shared control between humans and machine agents (e.g., [29]). Recent work has extended this framework specifically for supporting approval of MASS designs, based on design guidelines of major classification societies and maritime authorities [30]. They showed that tasks assigned to machine agents and human operators form a critical part of the "operational envelope" on which design approval hinges. The operational envelope also intro introduced the amount of time required to take over control from the autonomous systems and get "in the loop" as a key system property. This time is specified as "maximum response time [T_{MR}]," which in a given operational scenario is defined as the "maximum time the operator will need to reach the control position, gain situational awareness, and be ready to perform actions to maintain safety" (p. 4). In our case study interviews, we observed accounts of real takeovers. Most often, this included collision avoidance with small vessels. Other non-critical takeovers involved intervening for increased comfort of passengers in certain weather conditions. Building on the work of Rødseth et al. [30], our findings indicated that T_{MR} is not a fixed value. Depending on how freed-up attention was re-allotted, boredom or stretched resources would likely increase T_{MR}. Additionally, operators aboard *Korsvika*, who engaged in regular manual maneuvering practice, could also reasonably be expected to have lower T_{MR} than those aboard *Vikhammer*, who did not. Testing is needed to confirm these effects and whether they should be considered in the operational envelope.

It is also interesting to discuss the difference between how developers perceived work versus how it was actually carried out. To shed light on this topic, we examine a seemingly paradoxical result: despite expressly listing benefits of using the auto-systems, no operator perceived that it made them a better navigator. On the contrary, operators communicated their resentment towards a group they saw as undermining their primary control duties and safety responsibilities. As shown in the Findings, a group that we labelled "developers" (defined by one of the operators, Ola, as "Those who made the system") were antagonized and even resented. The gulf between operators and developers has been investigated before in the field of organizational science. Hollnagel & Woods [31] framed the issue as one of an abstract distance between “work-as-imagined” (development of operational work) and “work-as-done” (how that operational work is carried out). According to this explanation, only through better understanding of operator work can this distance be bridged, leading to improved organizational safety.

Multidisciplinary efforts may also be needed to build effective collaborative seafaring systems for MASSs. In Rahwan et al. [32] the authors argue that insofar that AI agents exhibit “machine behaviour,” human interaction with these agents will inevitably influence human behaviour. We observed this with “Betty,” the nickname two operators assigned to the auto-system, whose behaviour, among other things, was called “strange” and “nagging.” Rahwan et al. propose that incorporating disciplines traditionally outside of those that produce intelligent machines can serve to incorporate scientific methodologies and frameworks that lead to a better understanding of how this behavioural influence is taking place. In this vein, the authors underscore the need for techniques traditionally used in the quantitative behavioural sciences, like randomized experiments and observational inference.

System safety must also be considered. Leveson et al. [33] defines safety as an “emergent system property,” whose accidents can be understood as “the result of flawed processes involving interaction among people, societal and organization structures, engineering activities, and physical systems components” (p. 97). In the field of risk science, approaches inspired by systems engineering have been incorporated to address system safety. On such example is System Theoretic Process Analysis (STPA), which has emerged one of the foremost approaches for risk-based design of MASSs with human operator collaboration (e.g., [34–37]). Although these are promising directions, there is still a lack of concrete cases allowing for evaluation of risk-based approaches in real-world MASS implementations.

In the work presented herein, we have described the new concept of collaborative seafaring that is emerging in tandem with highly automated ship navigation systems. We have also highlighted some of its potential pitfalls in implementation. More work, however, is needed to explain its mechanisms. Among other things, future research will be motivated by the need to address mental underload caused by automation. Can this be counter-balanced by increasing operational complexity, for example by having a single operator responsible for multiple MASSs? We have also witnessed the effects on organizational structures, with evidence suggesting that procedures for regular manual practice may provide an effective safety control against automation-induced de-skilling. These are indications of a community advancing beyond considerations of first-order technology benefits and towards clear-eyed orchestration of these benefits in collaborative work.

5. Conclusion

This work aimed to identify and describe the emerging phenomenon of collaborative human-AI seafaring. Our motivation lay in uncovering the “nitty gritty” details of operators whose daily work has become influenced by the agency of intelligent machines. In our case study, ferry operators using recently developed auto-crossing and auto-docking technologies provided an opportunity to investigate this topic. Applying a mixed-methods approach, we identified emergent themes in the data that did not fit conventional paradigms of ship navigation. The study highlighted potential pitfalls when introducing machine agents into real-world seafaring work. To be sure, our study demonstrated that, at least aboard Ro-Ro ferries, tangible positive outcomes are indeed arising from implementation of highly automated navigation systems. The paradox, though, was that despite the benefits, operators collaborating with the auto-systems perceived that their abilities to safely navigate were unchanged or even hampered. The problem, we observed, lay in AI-interaction effects. Attention of operators, when freed up from manual tasks, was often re-focused on little else. Or, on the opposite spectrum, attention re-assigned to new roles served to stretch available resources to the resentment of operators. Among the latter group, there was an underlying belief that exclusive focus on immediate benefits of auto-systems could undermine overall system safety, serving the opposite of their intended purpose. These are pitfalls that, if avoided, will lead to safer implementation of MASSs and the lowering of barriers impeding further introduction of machine intelligence in ship operation.

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