Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio
 Published by Research Publishing, Singapore.
doi: 10.3850/978-981-18-8071-1_driver

Alarm and hand-over concepts for human remote operators of autonomous ships

Thomas Porathe

Dep. of Design, NTNU, Norwegian University of Science and Technology, Norway. E-mail: thomas.porathe@ntnu.no

Maritime autonomous ship systems are increasingly in the focus of maritime research institutions, especially in China and Norway. A lot of effort is put into development of technical systems based on artificial intelligence and machine learning. Still, for a long time, we will need to rely on that highly automated systems onboard to keep a human operator in the loop, albeit remotely. For long open ocean transits it is likely that one operator will oversee several ships, and with a mature automation the chance is that operators seldom will need to intervene thus losing skills and "ship sense". The situation for the human operator in the remote operation centre will likely contain one or several of the ironies of automation described by Bainbridge already in 1983 (deskilling, out-of-the-loop syndrome, automation surprise, etc.) The safety and reliability of an autonomous ship system will rely on this teaming between humans and automation. This concept paper intends to summarize some of the Human Factor's issues facing designers of the remote workplace in a Remote Operation Centre (ROC) where human operators after a long period of idleness suddenly is summoned to their workstation after an alarm from one of their autonomous ships. The question in focus is how can we make this a good workplace?

Keywords: autonomous ships, MASS, remote operation centre, human factors, human-centered design, unmanned navigation

1. Introduction

Autonomous unmanned ships have in recent years gained much intertest, especially in Norway and China are leading research nations within this field. Li et al. (in press), Porathe (in press). The author participated in one of the first autonomous ship projects MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) 2013 to 2015. The "autonomous ship" concept relies on the presence of a mature and reliable technology. The word "autonomous" implies the presence of some kind of future "artificial intelligence", but a simple suggestion of how artifacts can operate under their own control was given already in the classical antiquity by Ctesibios of Alexandria who built a self-regulating water clock. Russell and Norvig (2016). If a ship is to become "autonomous" it will need a very complex technology, and its behavior will (just like humans) not be entirely predictable. If their behavior is to be predictable (which we might assume that IMO, the International Maritime Organization, will mandate), they might in the end just be "highly automated". And automation have its problems, as we shall see next.

1.1. *Humans-out-of -the-loop (HOOTL)*

Vandoren claimed in 1998 that the control loop is the essence of automation. "By measuring some activity in an automated process, a controller decides what needs to be done next and executes the required operations through a set of actuators". How this can be done can be seen in the following example.

Between five and nine in the morning of 23 March 2019, 18 lubricating oil low-level alarms were registered by the four diesel generators on the cruise ship *Viking Sky*. Each alarm, having been acknowledged by the engine control room, was cleared within a few seconds and went back to normal. The four diesel generators of Viking Sky were huge and supplied not only the whole ship with power, but also the electrical motors driving the propulsion. The ship continued its journey with 1,373 cruise passengers and crew onboard. AIBN (2019). That would turn out to be a mistake.

Viking Sky was underway from Tromsø to Stavanger in Norway having skipped a stop in Bodø due to deteriorating weather. In the afternoon she reached the exposed waters of Hustadvika southwest of Trondheim.

The wind was by now south-westerly, severe gale to storm, 22-25 meters/second – about 50 knots – and with waves of 15 meters in the area around Hustadvika. Owing to the bad weather, the Norwegian coastal service and numerous local ferries had been cancelled and stayed in harbor. Alerts about the bad weather had been issued several days earlier by the Norwegian Meteorological Institute. DSB (2021).

No more alarms were registered until 13:37 when diesel generator four (DG4) registered an alarm indicating that the DG was shedding load as a result of low lubricating oil pressure. A few seconds later it registered a low lubricating oil pressure alarm. At 13:39, DG1 registered a low lubricating oil sump level alarm. A little over five minutes later, at 13:45, DG4 shut down followed by DG2 eight seconds later. DG2 was restarted after approximately 11 minutes, but shut down again along with DG1 at 13:58, causing a complete black-out and loss of propulsion. The ship was now in the hands of the elements.

Because of the wind trap created by the ship, and tidal currents with upward of nine knots, the ship was drifting rapidly toward land, an area known for its numerous shoals and reefs. *Viking Sky* was in dire straits. The captain transmitted Mayday and salvage resources were mustered by the Joint Rescue Coordination Centre in Stavanger.

So, what went wrong here? Although the incident happened in March 2019, the final accident report has still not been published as this is being written in April 2023, four years on. But based on an interim report from November 2019 by the Norwegian Accident Investigation Board, a report from the Norwegian Directorate for Civil Protection, DSB (2020), and media coverage we can puzzle together this probable scenario.

It is technical failure in the engine room, possibly due to "human error" by having too little lubrication oil in the diesel generators. If the diesel generators do not have sufficient lubrication, they are at risk of overheating and breaking down. You have such an alarm in your car. If this happens there is a possibility of severe damage to the engine that will be costly to repair. It could even cause other damage, possibly even start a fire. On *Viking Sky* the sensors communicated such dangerously low oil level/pressure on all four generators and based on this the automation shutdown all four generators resulting in a total loss of propulsion.

Apparently, this was completely automatic and there was seemingly no human involvement in the process. It was a safety function. One presumes that the designers reasoned that if the engine is going to break down, the prudent thing to do is to shut them down before it happens. In this case the engine shutdown occurred in gale force winds close to land. The ship dropped both anchors but kept drifting and was at the worst point ten minutes and a ship length from grounding when the engine crew, after about half an hour, managed to get first and then the other generators going. Eliot (2019).

What can we learn from this story? Apparently, engine designers had decided that if the engines were at risk, the proper thing to do was to force an automatic shutdown. Not asking the engine or bridge crew if this was a good place and time to stop the engines or if it could be deferred to later. (Sheltered waters was only half an hour away in this case.) No one had expected that this could happen to all four generators at the same time. But now it did. And it was not that the engines *were* to break down in the next couple of seconds, they were only *at risk* of doing so. There was lubrication oil in the sumps, only at a too low level and by sloshing around caused the low-pressure alarm. Designing automatic features where a human operator is not consulted are called Human-out-of-the-loop (HOOTL) design. We can compare this with Sheridan and Verplank's classical *Ten levels of automation* from 1978 where Level seven reads: "The computer executes automatically, then informs the human" or "ignores the human" (level 10). What would have been preferable in the *Viking Sky* case was a HITL (Human-in-the-loop) approach to automation. Giving the operators a chance to override the automatic feature and keep the engines running (even with the risk of serious problems) in the dangerous situation the ship was in.

This is relevant for the design of remote operation centers (ROC) for autonomous ships.

1.2. *Automation*

The reality of today's seafarers is far from the romantic notion of the past. It is an industrial work, often with long, boring workhours around the clock and very short breaks in industrial ports far from the city centers. In such an environment automation can be a good thing by removing humans from dirty, dangerous and dull tasks. It can also save costs by replacing humans and potentially make things safer and more reliable by removing the source of what is often called "human errors". But one must keep in mind that by doing so the source of "human ingenious recovery" is also removed, and the bottom-line outcome of that transaction is not self-evident.

In order to keep some of that human ingenuity in place the concept of autonomous unmanned ships contains a Remote Operation Centre. Porathe (2013).

2. Humans-In-The-Loop

The Remote Operations Centre (ROC), or sometimes Shore Control Centre is a land-based facility that will monitor (and sometimes, remotely maneuver) an autonomous ship. The ROC is in "constant control" of the ship. This is important from a legal point of view. The operator is "the captain".

The operators in the ROC plans and uploads voyage data to the unmanned ship and monitors the ship during the voyage. They have the ability to change the voyage plan by uploading a new plan, or by indirect or direct intervention change course or speed of the vessel. A ROC manages one or several autonomous vessels. If other ships call an autonomous ship over VHF radio, the call can be answered automatically or be relayed to the ROC. Porathe (2013).

How do we imagine the work as an operator in a ROC to be like? A possible proxy could be the work on the actual ship bridge where an Officer of the Watch (OOW) monitors an often already today automatic voyage. But automation today only takes care of the anti-grounding part of the job. The anti-collision part of the job is manual and much research is invested in finding automated behavior for avoiding to collide with other ships. In areas of high traffic density this will more or less completely engage the watch officer on the bridge. And would do so also for an operator in a ROC.

However, a larger part of the job in oceangoing ships are long watches when the ship sails automatically on an empty sea. In these situations, operators in the ROC could easily supervise several vessels and still be in the loop of what is going on. However, we know from many studies that humans are not good at monitoring well-functioning automation, and "boredom induced" accidents are a phenomenon. Nautilus International (2019). The chances are that we will encounter the same situation in a ROC.

3. Tasks in a ROC

So how can we design the workplace in the Remote Operation Centre to become a good working environment and accommodate for safe performance? I will discuss a few envisioned problem areas and tasks in the following: the out-of-the-loop syndrome and how the alarm screen can deal with it, how hand-over from automation to humans can be done, and finally the HITL versus HOOTL question.

3.1. *Out-of-the-loop syndrome*

While automation in many cases can improve the situation awareness of the operator by removing excessive workload, it can also act to lower situation awareness. Endsley and Jones (2012) use the phrase "out-of-the-loop syndrome".

When automation is performing well, being out-of-the-loop may not be a problem. And certainly, if you are monitoring several ships, being out-of-the-loop will be part of your workday. But when automation fails, or more probable, reaches conditions it is not designed to handle, the operator may be unable to detect the

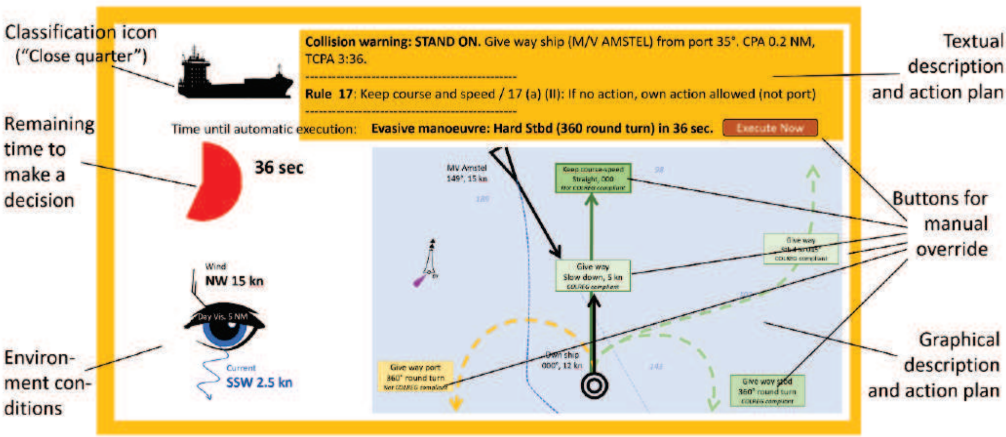

Fig. 1.An example sketch of how a Quickly-getting-into-the-loop display could look like. Porathe (2022a).

problem, interpret the information correctly and intervene in time. What happens when the human operator in the remote operation centre, after a long period of idleness suddenly is summoned to their workstation after an alarm from one of their autonomous ships? Then the foremost is a need for quickly getting into the loop.

3.2.*Alarm and quickly-getting-into-the loop*

In an earlier paper the author have described a "Quickly getting into the loop display" (QGILD). Porathe (2022a). This is a screen specifically designed to convey only the most critical information the operator need to understand the situation after an automated alarm call. Designing such a screen for all possible alarms will be easier said than done because it requires that the automation has correctly interpreted the situation (which will not be possible in all situations – "black swans"). But some design guidelines can be given to the information needed. The following sections refer to Figure 1.

3.2.1.*Classification*

It is an ordinary day in the ROC. Suddenly the warning chime is heard and the screen in Figure 1 appears on the large display in front of the operator. The orange border communicates it is a warning and no manual action is necessary, the top left icon communicates that there is an upcoming close quarters situation (possible collision) with a ship on the port bow that should give way. The icon answers the question of what is going on and shows the aspect of the ship (as it would have been seen from the bridge). The screen also gives a short analysis and presents recommended actions that can be executed manually by the operator or automatically by the ship.

Automatic classification will never be complete, but maybe machine learning might be a way to stive for better completion.

3.2.2.*Remaining time*

The red pie charts count down the time remaining until the automation will make the maneuver suggested (starboard round turn). If immediate action is requested by the operator, how much time does the operator have to decide before the fail-safe action by the system is commenced? And if the operator is unavailable to respond within the time frame (the response time is too short to get into the loop, the operator is unavailable, or the communication systems are down), what will the autonomous vessel do? The Control Option or Fail-to-safe mode.

3.2.3.Environmental conditions

The weather icon. What is the weather like where the drone ship is? Daylight or dark? Wind and current. Sea state. Visibility. Does Rule 19 for "restricted visibility" in the International Regulations for Preventing Collisions at Sea (COLREGs) apply?

3.2.4. *Automation transparency*

What is the ship automation's own analysis of the situation and what does it proposes to do (and will do if there is no intervention by the operator)? It may be a short textual information e.g. "Give-way vessel on port bow. Rule 17 applies. Keep course and speed". And/or it can be a graphical picture (camera view and/or chart view) showing the situation with own ships intended future route and other ships assessed route intentions. Porathe (2022b).

3.2.5. *Recomended and alternative actions*

If alternative actions are identified by the automation system they should be displayed in an easy to understand, if possible graphical format so that the operator with a click can direct or override the automated decisions. As in the case of *Viking Sky*: "Defer engine shutdown" (but keep showing parameters like oil pressure and cylinder temperatures)". Show other vessels possible maneuvering alternatives, e.g. by dashed lines. If new information is conveyed, e.g. by a radio call from another ship, clicking on the alternative route is a fast way of changing the automations decision basis. Other own maneuvering alternatives must be visualized and easy to pick by a mouse click for the operator.

As a last resort the operator should have an alternative to take "manual control" of the autonomous vessel.

In no circumstances should the automation give up and hand the ship over to an unprepared operator. Hand-over situations will be discussed next.

3.3. *Hand-over situations*

There will certainly be situations when the automation has no solution to an upcoming situation and will ask the operator in the ROC for advice or a decision.

A crucial question is then how long must this maximum response time be to give the operator a fair chance to get into the loop? Do we talk about six seconds or six minutes?

There is of course no precise answer to that question because it depends on how complex the situation is and how much out-of-the-loop the operator is. If you are a watch officer on the bridge of a ship and follow an upcoming situation you may be ready to intervene within a very short time span, and then seconds could be quite doable. But if you are in an ROC monitoring several vessels and you may have been engaged in another vessel for some time, minutes is more likely. Here it may be useful to introduce the notion of Operator Readiness Levels. Porathe (2020), Rodseth (2020).

3.3.1. *Operator Readiness Levels (ORL)*

The MUNIN project concluded that a Shore Control Centre probably would be a fairly large facility, managing many ships and the operators would be scheduled to monitor different numbers depending on the different factors like traffic intensity and fairway complexity. On the open ocean with very few ships around an operator was envisioned to monitor six vessels. Porathe and Costa (2014). In complex areas fewer ships and for mooring probably only one ship per operator. To manage a convenient workload a schedule for each operator and shift should be made so that port entrances, passage of narrows and congested areas are mixed with open ocean passages. This

Table 1. An example of a list of operator readiness levels. Operators could be scheduled for periods different readiness levels over a workday for a less stressful job. Porathe (2020).

Operator readiness levels	Maximum response time	
In control	0	Operator in-the-loop and at control station
High	3 min	Operator should be in-the-loop and close to the control station
Medium	15 min	Operator in the ROC ready to get in-the-loop
Low	1 hr	Operator home on call

will to a large extent be plannable depending on known circumstances as geography and normal traffic patterns. Thus a varied work day for and operator should consist of different ORLs, overseeing different number of ships. An example of how maximum response time could look like is shown in Table 1.

Operator readiness levels will make the automation aware of what response time the operator can be expected to demand, and tailor its behavior after that.

3.3.2.*Automatic control*

The normal mode of operation must be automatic control. The ship automation will decide, inform and execute decisions (if there is no intervention from the operator). For a mature autonomous ship system this must be the mode 99 % of the time.

But, automation may also produce surprises, as we saw in the *Viking sky* incident earlier, where the engine crew presumably did not realize that the warnings might lead to a sudden shutdown. And the more complex the systems are, the more difficult it will be to understand what is happening (*coupling*). And if artificial intelligence is used, one must be very sure that the ship behaves according to COLREGs and in a way that is understandable for humans. In the ROC and on manned vessels in the vicinity.

We know that communication outages will happen. And requests for help from the automation to the ROC will be unanswered. This means that the automation will be ultimately in charge and must come up with a solution. It may be difficult to live up to the words from the US Navy admiral that said all "AI warships must obey". Konrad (2023).

Ultimately there need to be a way of taking "manual control".

3.3.3.*Manual control*

Is a completely manual mode possible for remote operators that has long lost the skill to maneuvering a ship? Probably not. Goal based maneuvering (give a heading and a speed) or click-and-drag waypoints, might be a safer way to e.g. avoid a group of fishing boats.

But emergency control using a joystick that works like in a DP (dynamic positioning) system, where you press the top button to take manual control, turn the stick to control heading and use lateral tilting of the stick in a helicopterlike fashion to translate forward and astern or sideways. See Figure 2.

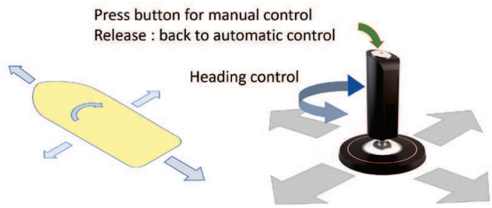

Fig. 2.Hand-over from automatic to manual control: by pressing the button om the joystick automatic operation is suspended and manual goal-based control of the ships maneuvers.

3.4.*The anti-grounding task*

The navigation task consists of anti-grounding and anticollision. The Electronic Chart Display and Information System (ECDIS) together with a satellite-based positioning system and the autopilot forms the essential anti-grounding automation. As long as there are reliable digital navigation charts, reliable satellite coverage, a working autopilot and the weather is not too extreme, this is a technology that is well tested and mature. Many ships navigate automatically with no manual control as long as there are no other ships around.

3.5.*The anti-collision task*

Collision avoidance has been called a game of coordination, where navigators on different vessels must choose mutually compatible strategies independently. Cannell (1981). To help in this coordination game there are a set of 41 rules in the COLREGs. However, in some situations they may be ambiguous, and they does not give quantitative enumerations of how an evasive maneuver should be conducted other than it should be "early and substantial". Other quantitative examples are expressions such as that actions should be taken "in ample time" and with regard to the observance of "good seamanship". Rule 2(a), for instance, requires that you to follow both the rules and "the ordinary practice of seamen". It will be difficult for the programmers of automation to generically find the right parameters and many of these parameters change with the complexity of fairways, proximity to land, weather and traffic density. Estimations will have to be done – which might lead to misunderstanding between autonomous ships and human operated vessels. (A precise passing might be efficient by the automation but provocative and annoying by a watch officer on a passing vessel.) Ultimately, automatic decisions leading to accidents will have to be brought before a court of maritime law – just like with conventional ships today.

The anti-collision task will be one of the most difficult hurdles for autonomous ships to overcome and constraining the traffic patterns though traffic separation, route exchange, Moving Havens (traffic slots) and other measures that makes traffic coordination predictable might be necessary. Compare the benefits of the land based road system.

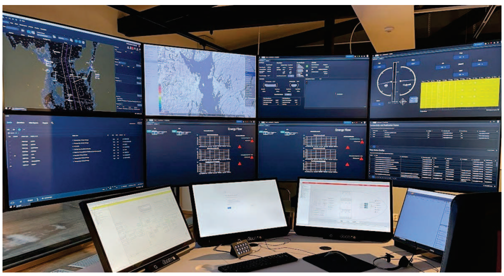

Fig. 3.The display of one operator station in Massterly's Remote Operation Centre in Horten for the Asko and Yara Birkeland autonomous ships. Photo by the author.

3.6.*Information needed in the ROC*

Figure 3 shows one of the operator stations in the ROC of the two Norwegian Asko ferries that autonomously cross the Oslo fjord several times a day. Still they have a bridge crew onboard but the goal is to make them automatic and unmanned.

When everything is calm and working normally, the overview of information may be very clear, offering the operator a view of most systems. But when things start to go wrong and cognitive tunnelling sets in, information overload may be a likely result. Here information design will have a crucial role to play. Information needs to be tailored in such a way that only necessary information is shown for the task at hand. And again, this in turn depends on that the automation that governs the information sharing system have correctly understood the situation. Something that will not always be possible. This will be a large and difficult research task for the future.

3.7.*Control sharing, HITL vs. HOOTL*

An early statement in this paper was that Remote Operation Centers for autonomous ships must be designed with the humans in the loop (HITL). And we read about the incident with the cruise ship *Viking Sky*. One may imagine that the operators in the Engine Control Room was surprised when all four generators automatically shut down, a human-out-of-the-loop event (HOOTL).

The accident investigation is not yet published, but it is easy to come to the conclusion that in this case a HITL design would have been preferable. And it is easy to conclude that HITL is the preferable paradigm in ROC design as well.

At the same time, we have heard that the autonomous ship automation must be able to make its own decisions in the end, in case of the human operator not being available, due to being out of the loop or disconnected. That is, the automation must also be able to go HOOTL. A tricky issue. The automation must dynamically be able to climb up and down Sheridan and Verplank's "Ten levels of automation".

4. Conclusions

This paper has tried to summarize some research findings regarding Human Factors design issues in Remote Operation Centers for autonomous ships from the MUNIN project, which started in 2013, to several present day Norwegian autonomous ship projects. A short paper like this can only give a brief glimpse of some problems, but they are pointing to areas which are under-researched and needs further attention.

What information is need for the operator to get quickly into the loop? How is control shared between the human operator and the automation? How is the hand-over from automation to humans done? What is the envisioned hand-over time? Are we talking about six seconds or six minutes? Is a completely manual mode at all possible? And if not, what semi-automatic control options are available?

At the Shore Control Lab in Trondheim, Norway some of this research is conducted. Shore Control Lab (2023).

Acknowledgement

The research has been conducted within several projects funded by the Norwegian Research Council (SFI AutoShip, LOAS and HUMANE) which is hereby gratefully acknowledged.

References

AIBN, Accident Investigation Board Norway (2019).*Interim report 12 November 2019 on the investigation into the loss of propulsion and near grounding of Viking Sky, 23 March 2019*. https://havarikommisjonen.no/Sjofart/Undersokelser/19-262?iid=27466&pid=SHT-Report-Attachments.Native-InnerFile-File&attach=1 [Acc. 2023-04-20]

Cannell, W. P. (1981).Collision Avoidance as a Game of Co-ordination. *Journal of Navigation* 34(2): 220-239.

DSB, The Norwegian Directorate for Civil Protection and Emergency Planning (2021). Assessment of the Viking Sky Incident. https://www.dsb.no/globalassets/dokumenter/rapporter/assessment_of_the_viking_sky_incident.pdf [Acc. 2023-04-20]

Eliot, L. (2019). Human In-The-Loop Vs. Out-of-The-Loop in AI Systems: The Case of AI Self-Driving Cars. AItrends, April 9, 2019, 17538 https://www.aitrends.com/ai-insider/human-in-the-loop-vs-out-of-the-loop-in-ai-systems-the-case-of-ai-self-driving-cars/ [Acc. 2023-04-20]

Endsley, M. R., and D. G. Jones (2012).*Designing for Situation Awareness: An Approach t. o User-Centered Design, Second Edition*. CRC Press

Konrad, J. (2023). US Navy Admiral Says AI Warships 'Must Obey'. gCaptain, 6 April 2023. https://gcaptain.com/us-navy-admiral-says-ai-warships-must-obey/?subscriber=true&goal=0_f50174ef03-cd008225da-139897621&mc_cid=cd008225da&mc_eid=6a1fc80601 [Acc. 2023-04-28]

Li, Z., D. Zhang, B. Han, and C. Wan (in press).Risk and Reliability Analysis for MASS: A Bibliometric Review of literature from 2015 to 2022. *J. of Accident Analysis and Preventions*, (in press).

Porathe, T. (in press). Overview of recent research. In M. Lutzhoft, J. Earthy and E. s: Petersen (Eds.) *Human-Centred Autonomous Shipping*. CRC Press.

Porathe, T. (2022a).Remote Monitoring of Autonomous Ships: Quickly Getting into the Loop Display (QGILD). In K. Plant and G. Praetorius (Eds.) *Human Factors in Transportation. USA: Applied Human Factors and Ergonomics International (AHFE International) 2022* pp. 691-697.

Porathe, T. (2022b).Collision Avoidance for autonomous ships (MASS): making assumptions about other ships intended routes. In M., C. Maria, E. Patelli, L. Podofillini, and S. Wilson (Eds.) *Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022).* Research Publishing Services 2022, pp. 752-759

Porathe, T. (2013). *Error and human intervention report in the context of autonomous vessels*. Deliverable D7.1 in the EU project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks).

Porathe, T., K. Fjortoft, I. L. Brattbergsengen (2020). Human Factors, autonomous ships and constrained coastal navigation. *IOP Conf. Ser.: Mater. Sci. Eng.* 929 012007. https://iopscience.iop.org/article/10.1088/1757-899X/929/1/012007 [Acc. 2023-04-28]

Porathe, T. and N. Costa (2014). *Organizational lay-out of SOC (Shore Operation Centre).* Deliverable D7.3 in the EU project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks).

Rodseth, O (2020) Constrained autonomy for a better human-automation interface. In S. O. Johnsen and T. Porathe, *Sensemaking in Safety Critical and Complex Situations: Human Factors and Design*. CRC Press.

Russel, S. and P. Norvig (2016).*Artificial Intelligence: a Modern Approach* (3rd ed.). Pearson.

Nautilus International (2019). Maritime malaise – how unstimulating work is creating unhealthy crews and unsafe ships. https://www.nautilusint.org/en/news-insight/telegraph/maritime-malaise--how-unstimulating-work-is-creating-unhealthy-crews-and-unsafe-ships/ [Acc. 2023-04-20]

Sheridan, T. B., and W. L. Verplank (1978).*Human and computer control of undersea teleoperators.* Massachusetts Institute of Technology Cambridge Man-Machine Systems Lab.

Shore Control Lab (2023). NTNU, Norwegian University of Science and Technology. https://www.ntnu.edu/shorecontrol [Acc. 2023-04-30]

Vandoren, V. J. (1998). Control loop is automation essence. Control Engineering, https://www.controleng.com/articles/control-loop-is-automation-essence/ [Acc. 2023-04-30]