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Autonomous Ships: A research strategy for Human Factors research in autonomous shipping

Thomas Porathe

NTNU, Norwegian University of Science and Technology, Trondheim, Norway
thomas.porathe@ntnu.no

Abstract. The intention of this paper is to present some identified tasks for Human Factors and design research within the area om Maritime Autonomous Surface Ships (MASS). It targeted for the research project SFI AutoShip at NTNU in Trondheim but might also be of some general interest for the HF and design community within the maritime domain. The research areas deal with human-automation interaction as it might manifest itself between operators and the human-machine interface in the Remote Operation Centre (ROC), between autonomous and conventional ships at sea and between crews of partly manned ships and the automation. Eight research tasks has been identified and is presented in this paper.

Keywords: Human Factors · Human-automation Interaction · Autonomous ships · Maritime Autonomous Surface Ships · MASS

1 Introduction

Autonomous ships are in focus for research in many places. The shipping industry seems to be open for this new technology. A goal is unmanned navigation. The resent pandemic with problems relating to international transfer of crews, might add to this interest. The International Maritime Organization (IMO) added Maritime Autonomous Surface Ships (MASS) to its agenda in 2019 [1]. At the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, a new Centre for Research and Innovation named “SFI AutoShip” started in 2021 with the aim of supporting the Norwegian industry’s attempts to realize autonomous shipping [2]. The center’s research will cover four use cases: ocean shipping, short sea shipping, ferries and offshore operations. The project involves several work packages focusing on areas like sensor- and decision-making systems, reliable and secure data infrastructure, models and tools for risk management, cost-effective and environmentally friendly sea transport and fostering of innovation and commercialization. However, as unmanned systems involve humans to a high degree, Human Factors (HF) and the Remote Operation Centre (ROC) will be the focus of one work package. This work package is led by the author and this paper aims at discussing potential research tasks envisioned for the coming eight years.

2 Background

Humans will interact with MASS from the bridges of conventional, manned, ships as well as from control rooms and as passengers on unmanned ferries, to mention just a few examples. But humans are also involved in design, construction, planning, maintenance of the MASS. The conclusion is that Human Factors will play an important role in the development and operation of MASS systems.

This author first encountered the idea of "autonomous ships" through the MUNIN project [3] in 2012 leading the research on what was then called the Shore Control Centre. The case at that time was a 200-meters long Handymax dry bulk carrier transiting a transatlantic route between the UK and Venezuela. Because the choice was made to assume having a pilot and crew taking the ship to and from port to pilot-drop-off/pick-up point, we only looked at autonomous navigation for the open ocean passage. In the spring of 2013, I presented the project for the IALA ENAV committee which over 100 members from coastal states all over the world. The members all laughed and said, "Come back in 25 years!". That was eight years ago. And now Norway have already built the "world's first autonomous container feeder" [4].

This autonomous, 60-metres long container shuttle was delivered in autumn of 2020 and testing will commence this year. The same operator has also signed a contract for two autonomous trailer ferries [5]. These ships are all planned for unmanned navigation.

Although research today mostly focuses on the final goal of unmanned and "autonomous", or highly automatic ships [6], the reality will most certainly be one of gradual development and stepwise implementation. One can assume several phases such as: 1) decreased manning with remote monitoring/assistance from a ROC and some level of automatic navigation. But having too small crews onboard might cause social strain and even safety issues which might lead to 2) completely unmanned, highly automatic ships partly navigated by remote control. Not until a completely mature technology has developed, can we expect 3) fully "autonomous", unmanned ships, however, still monitored from shore. During those phases, humans will play an important role and classical Human Factors problems like, fatigue, information over- and underload, out-of-the-loop syndrome, automation irony and surprise, etc. will need attention [7].

I will in the following sketch some problem areas that I think SFI AutoShip should give attention in the coming year of HF research for MASS.

3 Automation

The lead word behind MASS is *automation.* Automation is supposed to increase safety and efficiency and reduce cost and accidents. MASS is expected to be *at least as safe as a manned ship,* which was the benchmark threshold we used in the MUNIN project. Looking at it from the human side: in order to be able to succeed with that, the "automation" needs to learn a lot of things today taught at maritime academies.

At maritime academies cadets are taught to consider navigation as the two-folded task of anti-grounding and anti-collision. Anti-grounding has to do with position fixing and wayfinding from A to B without hitting reefs and shallows in all possible weather conditions. Anti-collision has to do with courteous coexistence with other ships based on a common interpretation of rules and regulations, and especially soft, cultural values like “safe speed,” “early and substantial action” and “the ordinary practice of seamen” [8]. Both these tasks need to be automated to realize MASS.

The task of anti-grounding is already today highly automated on a modern ship. Technology tells the navigator where he or she is both in the world and in relation to shoals and dangers in fog or darkness. Electronic voyage plans are automatically safety checked for under keel clearance and autopilots in track-following mode will automatically steer the ship along the planned route, compensating for leeway caused by current and wind. This is done with high precision as I observed on the bridge of one of the Norwegian Coastal Express ships as she negotiated the narrows of the archipelago during one of her voyages up and down the Norwegian west coast. With the cross-track distance set to 50 meters port and starboard an alarm would sound if the ship ventured out of her planned corridor, which was rare. However, the bridge was manned by a watch officer and a look-out at most times and collision avoidance had to be done “manually”. With this anecdotal evidence we could say that automatic navigation to some extent already exists. The real trickery of docking a huge ship with is also studied and commercial “auto-docking” features are already claimed by some companies [9].

The anti-collision task will, however, be a harder nut to crack. Radar and AIS gives very good situation awareness, also in darkness and fog, and radio allows communication with other ships and shore, still collisions happen. Usually they are caused by misunderstandings, different interpretation of rules or sheer neglect. What is often referred to as “human error”. Anti-collision will be a great challenge for automation, especially considering that automation must coexist with conventional, manned ships for a long time to come. One way of simplifying the task, both for humans and automation would be by simplifying the traffic environment.

3.1 Research Task 1: Simplification of the Traffic Environment.

The practice of following predetermined routes for shipping started at the end of the 18-hundreds and was adopted, for reasons of safety, by shipping companies operating passenger ships across the North Atlantic. The IMO installed a so called “Traffic Separation Scheme” (TSS) in the English Channel in 1967 and a significant fall was seen in the number of collisions between ships on opposing courses [10].

The EU project ACCSEAS presented in 2015 a “North Sea Region Route Network Topology Model” (NSR-RNTM) [11]. Such a complete North Sea TSS would deconflicting ship traffic much to the benefit of MASS automation as well as ship traffic in large [12].

Another way of decreasing collisions could be by using technological e-navigation services to increase the predictability of ship movements.

3.2 Research Task 2: Increased Predictability of Ship Traffic

In 2006 IMO approved a proposal to develop an “e-Navigation strategy”. The objective of the proposal was to “develop a broad strategic vision for incorporating the use of new technologies in a structured way and ensuring that their use is compliant with various navigational communication technologies and services that are already available, with the aim of developing an overarching accurate, secure and cost-effective system with the potential to provide global coverage for ships of all sizes," [13]. Two new innovations that came out of some e-navigation projects like the EfficienSea [14], MONALISA [15] and ACCSEAS [16] was *route exchange* and *moving havens*.

Route Exchange. All large ships are by regulation required to do a plan of its voyage before departure. This voyage plan resides electronically in the ships navigation system. Route exchange means that all ships share their voyage plans. This can be done by sharing route-intentions (each ship transmits a number a waypoints ahead of time so that other ships can see their intentions). It can also be done on a larger scale, used for Ship traffic Management by letting a central coordination mechanism plan traffic, much as is done by ATC in the aviation domain [e.g. 17, 18].

Moving Havens. Voyage plans are basically a two-dimensional geographical map construct. But by adding an estimated time of arrival (ETA) in each waypoint a ship's voyage can also be planned in the time domain. We researched this feature in the MONALISA project and the result is the so called RTZ-format for route exchange, approved by the International Electrotechnical Commission in 2015 [19]. The planned whereabouts of each ship is visualized by a box with the width of the set cross-track distance and the length of the desired temporal precision and the traffic situation. The Moving Haven is used by human navigators onboard and VTS ashore to see that ships are on track and for a coordination mechanism to ensure that separation is kept forward in time [20]. Moving Havens will be important for the predictability of a ship and MASS traffic, especially in constrained area with high traffic density.

Mostly, development of automation will be a technological endeavor involving machine learning and artificial intelligence which is out of the scope of this paper, except when it comes to the human-machine interaction which I will focus on in the next section.

4 Remote Control

A crucial entity in this new ecosystem will be the shore based Remote Operation Centre (ROC). The ROC will have two task which I will discuss separately below: monitoring and remote control.

4.1 Research Task 3: Situation Awareness in Remote Monitoring

The interaction between technology and the human operator through the Human Machine Interface (HMI) will be one problem area in the ROC. A keyword here is Situation Awareness. How well can the operator be kept in the loop by the interface? In the MUNIN project we identified some 145 data point that must be sent from the ship to the ROC for the operators to monitor the navigation of the ship (not including detailed engine monitoring). [21]. This interface must be organized in a standardized way that allow easy information access. This will be a crucial research task.

The organization of work will also be of great importance. Workload must be kept on an acceptable level. Not too low and not too high. By observing work on existing ship bridges as a proxy one can see that workload onboard differs greatly. From the hectic and information loaded approach to a port to the complete boredom on the bridge during an ocean passage with no other ships withing a 60-mile radius.

One Operator, Multiple Ships. We can assume that operators monitoring ships on ocean passage can monitor several ships at the same time. In the MUNIN project we, as a start, made the assumption that 6 ships could be actively monitored for such low-workload phases. The rational was that an operator should return to each ship for 10 minutes every hour, monitoring some basic parameters such as progress, traffic situation, system performance and weather conditions. On an ocean passage in 10 knots the traffic situation for the next hour would be well within what could be overviewed by the radar during each instance and the human working memory should also be able to keep the status of 6 ships concurrent. However, the number of ships monitored must vary dynamically depending on the traffic situation. A well-balanced workload should be the goal and that was why a ROC must consist of several operator that can be ready to step in when necessary.

In the other end of the spectrum, for a MASS approaching port the relation between operator and ships must probably be 1:1. In order to support an even workload the concept of Operator Readiness Levels was introduced.

Operator Readiness Level (ORL). In the above we assumed active monitoring. But research shows that humans are very bad at monitoring well-functioning automation. One must presume that active monitoring could well become *passive monitoring*. To visualize and plan the need for attention, both for the operators themselves and for the supervisor and colleagues in the ROC the concept of Operator Readiness Levels is proposed [20]. Based on the traffic situation the need for operator attention should be considered. As mentioned above, on the open ocean with no ships within a 60-mile radius, the ORL might be set to 1 hour. ORL could vary from *red* (in control), trough *orange* (e.g. 3 min), *yellow* (e.g. 15 min.) to *green* (e.g. 30 min or one hour).

Of course, that goes for one ship. If the operator is responsible for several ships the ORL must be calculated accordingly.

An Early Warning Look-Ahead function should be researched that dynamically update operators ORL well in advance to avoid surprises when an operator suddenly needs to make decisions when not really knowing what is going on. But as a back-up research also must be done on a Quickly-getting-into-the-loop display.

4.2 Research Task 4: Quickly-Getting-Into-the-Loop Display (QGILD)

When something goes wrong and the automation asks the human operator for input the chances is that the operator might not be aware of what is going on and will need some time to understand the situation. The phenomenon will well-known and is called out-of-the-loop syndrome [22]. There will then be a need for a standardized quickly-getting-into-the-loop display where an operator could find the crucial information to quickly understand the situation. Designing such a standardized display will be an important contribution.

As mentioned in the beginning I assume that the implementation of automatic navigation will come stepwise: by installing an augmented sensor system, pared with some intelligence/elevated automation and a connected ROC. For these "partly manned ships," communication between the ROC and anywhere on the ship will be important.

4.3 Research Task 5: Remote Operator - Bridge Interface (ROBIN)

In the very beginning one can assume that ship operators will start carefully to subscribe to ROC services. It might start by letting the ROC replace the junior watch stander during the small hours on an ocean leg. If problems arise, ROC will alert a senior officer onboard? Or if ROC has the watch and the captain comes on the bridge and wants to know what is going on? Or if the remote operator wants to get in contact with the captain or the chief engineer? If a vessel is unmanned but has maintenance crew onboard, how is communication done? The research question here is if there is a need for a communication system with physical manifests (cameras and monitors?) onboard a MASS, partially manned or unmanned?

4.4 Research Task 6: The Glass Box: Automation Transparency

When automation have the conn (is in control), decisions will be made by algorithms programmed to comply with assumptions about the best course and speed through the current sea state, COLREG compliant collision avoidance maneuvers considering the current traffic situation, best route to reach next waypoint with given ETA, etc. etc. Elaborating great many parameters and constrains will be done in inside the navigation computer. Depending on the level of automation the decision will eventually be executed (or suggested to an operator who have the option to execute it). For mature MASS navigation we must assume that execution will be done most autonomously by the artificial intelligence (AI) navigator. Today it is difficult for AI to "explain" its way of thinking for a human. Mostly the decisions are made in a "black box". In computer science this problem area is called Explainable AI (XAI) [23]. For a navigator onboard or in a ROC, working together with an AI it will be important that the AI is transparent about how it "thinks", that its decisions are transparent and that alternative decisions are easy to execute. The AI must work within a transparent "glass box". However, this is easier said than done. This will be an important research area.

4.5 Research Task 7: Human Intervention and Handover

Automation Transparency is also closely tied to the area of human intervention. When the AI calls the operator for help, as we touched upon earlier, the operator will need some time to get knot the loop. But also, when the operator judges that the AI is not doing a good job and needs to intervene. In this area is a lot of ethical considerations buried.

4.6 Research Task 8: Interaction with Conventional Ships at Sea

Closely tied to the task of automation transparency is MASS interaction with conventional, manned ships. Is the MASS going to signal its intentions to other ships in the vicinity? Is MASS going to carry some signal indicating that it is presently under "autonomous control"? And if so, what should that mean?

5 Conclusion

The intention of this paper is to present some research tasks for the Human Factors and design research within the area om Maritime Autonomous Surface Ships. It is targeted for the Center for Research driven Innovation AutoShip at NTNU in Trondheim but might also be of some general interest for the HF and design community within the MASS domain.

The research areas deal with human-automation interaction as it might manifest itself within the Remote Operation Centre, between MASS and conventional ships at sea and between crews of partly manned ships and the automation.

The following eight tasks have been identified so far:

Research Task 1: Simplification of the Traffic Environment.
Research Task 2: Increased Predictability of Ship Traffic
Research Task 3: Situation Awareness in Remote Monitoring
Research Task 4: Quickly-Getting-Into-the-Loop Display (QGILD)
Research Task 5: Remote Operator - Bridge Interface (ROBIN)
Research Task 6: The Glass Box: Automation Transparency
Research Task 7: Human Intervention and Handover
Research Task 8: Interaction with Conventional Ships at Sea

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