Human-Automation Interaction for Autonomous Ships: Decision Support for Remote Operators

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ABSTRACT: At NTNU in Norway an 8-year research project has been established to (among other things) research the interaction between humans and unmanned, autonomous ships. The human will become even more important when ship operator will be located remotely in shore control centers ashore. This concept paper will take a closer look on remote decision-making by operators monitoring several ships. How can interface design help them to get quickly into-the-loop when something unexpected suddenly happens? I will in this paper suggest keeping a copy of the AI expert-system controlling the ship, updated and running in parallel in the control center to keep the operator's situation awareness during short communication glitches. Also, to design a "quickly-getting-into-the-loop-display" which automatically will appear in an alarm situation, allowing the operator just-in-time and simple-to-understand information. I will also stress the important of the concept automation transparency.

1 INTRODUCTION

At the Norwegian University of Science and technology (NTNU) in Trondheim a new centre for research driven innovation has recently received 8 year-long funding by the Norwegian Research Council. The name of the centre is SFI AutoShip and the research focus will be on autonomous ships with four different use cases: a) deep sea bulk shipping, b) short sea container shipping, c) ferries and d) offshore support operations. The centre is divided into several work packages focusing on problem areas within this new technology: 1) automation and remote sensing, 2) communication and digital infrastructure, 3) human factors and remote control centers, 4) safety and assurance, 4) sustainable operations and 6) innovation and commercialization.

After a resent presentation of the scope of this autonomous ship center a member of the audience asked a question about how we would approach navigation and ship handling in waters where local knowledge of how conditions and weather will affect a vessel are generally used? How will the "automation" know about local peculiarities? For instance, bathymetry which may create wave patterns during different weather conditions?

1.1 *Knowledge repositories in the past*

The question is very much to the point and reminded me of a story my grandfather told me in my childhood. Along the Swedish west coast where I grew up, there are some places where the archipelago opens, and the inner fairway is exposed to the rage of the open sea. Islandsberg is one of these places and I was always on my toes when we passed there in my grandfather's small cutter, even if the weather never was really bad. Many times, he told me of his father,

my great grandfather, who had been captain on a coastal express steamer trafficking the area in the 1930's. He said that passing Islandsberg in a westerly storm took some nerves, because of the fearsome chaos of braking waves rolling in over shoals from the open sea and reflecting back from the steep cliff. But, if you had these nerves you could find smooth water some 40-50 meters out from the cliff where the waves cancelled each other in a valley of "dead seas".

Where do this knowledge go when those who remember are gone? Some of it is rightly lost because new, larger ships are not affected by weather and wind in the same way, and, as in this case, goods and passengers are not transported along the coast in the same way anymore. But some knowledge is collected in "expert-systems". It could be old analogue expert-systems like for instance sailing directions. The sailing direction is a textual description of a voyage. It mentioned landmarks, courses and warned for specific local weather and sea conditions. So, for instance the British Admiralty sailing direction for the Norwegian coast puts it this way for an area not fare from Trondheim:

"Area 11, Hustadvika (63°00.00'N 7°00.00'E) is a notoriously dangerous area; the coast is completely exposed to the weather and extensive shoals lie offshore. Strong winds from SW to NW raise a large steep swell with hollow breaking seas, especially during the out-going tidal stream. These conditions are likely to be particularly severe in the area of Budadjupet between Bjørnsund (62°53.75'N 6°48.96'E) and Kolbeinsflua, 5 miles NNE. Breaking surf is reported to occur throughout the whole area." [11]

The sailing direction was the major medium for communicating navigational information to the mariner until the end of the eighteenth century, when its function was partly overtaken by the nautical chart. A nautical chart is a container for geographic knowledge. A nautical chart "represent the accumulation of more observations than any one person could make in a lifetime. It is an artifact that embodies generations of experience and measurements" [6].

The experience of past generations of seafarers are also promulgated in maritime academies where active or ex seagoing officers teach young apprentices based on their experience. Assuming future autonomous, unmanned ships are successful, where will then the experience come from? At the millennium change 1900, when the era of sail transitioned to the era of steam, cadets still had to have experience from commercial oceangoing sail ships to get their master's certificates. As the sailing ships were getting scarce this became a business opportunity for the ship owner Gustav Eriksson from Mariehamn in Finland which manned the last fleet of three and four masted iron windjammers on the wheat rout between Australia and the UK with paying apprentices (as well as a small safety crew). Maybe we will see the same again, if the number of manned merchant ships start to decrease? Or maybe the question is if we can gater previous generations of local and seagoing experience in a computerized "expert-system"?

1.2 The expert-system

The question of using expert knowledge collected in huge databases came in focus with the development of computers in the 1960's and 70's. At Stanford the Heuristic Programming Project started to investigate if expert-systems could be useful in analyzing chemicals and for medical diagnoses. [9]

Using expert-systems as decision-analyst and decision-maker is part of the Artificial Intelligence domain. I will in this paper use the term "expert-system" instead of the more general "AI" in order to emphasize its knowledge-based repository of maritime experience, which I think will become a commodity in short supply in the Remote Operation Centers (ROC) of future autonomous shipping.

2 THE REMOTE OPERATIONS CENTRE

In the MUNIN project I too, where I took part in drawing up the general framework for what was then called the Shore Operations Centre (SOC). Remote operator were to actively monitor up to six ships during relaxed conditions from the safety of a computer console ashore. Sensors would give them the necessary information about the state of the ships out there on the oceans, about winds and waves, engine performance and radar should detect traffic in the surroundings. Will it mean that remote operators no longer need the experience of how a hull performs in different wave patterns? Risks of broaching in following seas, or slamming if you head too fast into breaking waves? Can this experience be contained in computerized expert-systems? Can it be derived from experience collected through machine learning and harbored in "Artificial Intelligence"? Well, we don't have that answer to that yet. Still, we got to continue designing as if these problems can and will be solved.

Some of that has already been done. The Electronic Chart and Information Display System (ECDIS) with the digitalized Electronic Navigational Charts (ENC) are an example. Sailing directions are also digitalized, and attempts to make them smarter is underway, e.g. the embryo of a new interactive version of The Norwegian Pilot [7]. One wants to foresee future expert-system that can produce contextualized knowledge and experience form generations of mariners in an easy to use manner when the situation demands decisions to be made.

Lisanne Bainbridge in 1983 talked about the Ironies of Automation. We automatize what we can (the simpler tasks), but when it gets really complicated automation cannot cope and we are up for a surprise when it suddenly hands us the full responsibility. I am thinking about an example from the aviation domain: the Air France 477 accident in 2009.

2.1 Effects of automation

The night of the 1st of June 2009 Air France fight 447 from Rio to Paris, disappeared in the middle of the Atlantic Ocean. And with it, 228 passengers [2].

The plane was in mid air over the South Atlantic approaching the Inter-Tropical Convergence Zone, the area where air masses coming from the different hemispheres converge at the humid equatorial latitude, with electrical storms as a result. Suddenly the automatic flight management system lost speed input from the triple redundant pitot tubes (which were all clogged by ice) and handed, what had up to then been a fully automatic airplane, into the hands of the relatively inexperienced junior pilot flying.

The accident investigation tells a horrifying story of mismatch between the automation interface and the pilots trying to make sense of what they saw on the screens. The highly automated flight system, which interfaced the human and the machine through sophisticated computer programs that in this case was difficult to understand and handle correctly. The automation can prevent human mistakes when everything works as planned by the engineers, but became incomprehensible for the same operators when computers did not receive proper inputs and went blind [4].

After the accident, accusations were made regarding loss of basic skills of manual flight (e.g. [10]). Was it that liner pilots had lost their skills and their capability to manually fly a plane, because of the use of autopilot and of the overwhelming technology? Bainbridge [1] remarked that skills deteriorate when not used and a formerly experienced operator monitoring an automated process may well have turned into an inexperienced one. Then when manual take-over is needed there is likely something wrong, so that unusual actions will be needed to control it, and one can argue that the operator needs to be more rather than less skilled.

When designing a new workplace for marine watch officers moving into a shore-based Remote Operation Centre, one might envision such a loss of skills. How long will it take for an experienced deck officer to become unexperienced? Having forgotten the inertia and dynamics of maneuvering a big ship in heavy seas or birthing in an intricate dockland? Can this be avoided? Can we replace individual experience with expert-systems? The challenge is enormous. Let us do some design sketching of such systems to support decision-making in a ROC.

I will sketch two concept solutions: how to keep the operator in the loop during communication glitches and how to quickly bring the operator into the loop if he or she has been "absent" and there is a sudden alarm situation.

3 THE DECISION SUPPORT SYSTEM AND ITS "DIGITAL TWIN"

Let us assume that we can collect this nautical experience in an expert-system capable of making decisions and transparently showing the monitoring operator its current status of knowledge (the input from sensors on the remote ship) and what it is planning to do (its intentions, plan A, B and C…).

Let us assume that all necessary data from the ship is communicated to the ROC through some kind of communication system (satellite, 5G, Maritime Broadband, etc.). Our experience tells us that we will have communication glitches or outages from time to time. In the MUNIN project we said that a MASS that has lost communication with its control centre should stop in a "fail-to-safe" mode. Now, stopping in the middle of whatever situation the vessel might be in might not always be the smartest action. Smarter would be to go to a "minimum risk conditions" [5], meaning that the ship will do what is best given the current circumstances: in the middle of the ocean, with no other ships within 30 nautical miles, the ship might just as well carry on its course for some time waiting for communication to come back. But in a densely trafficked shipping lane in the English Channel, the ship could check for oncoming vessels on its starboard quarter and then proceed out of the Traffic Separation Scheme and stop and hover on its DP (or anchor) while sending relevant pre-recorded messages on VTH channel 16 and hoisting relevant signals. And most important of all is that we realize that, having lost communication, decisions must made by the expert-system on the ship alone. The automation will have the final say.

What if we see it from the remote operator point of view: suddenly the communication link with the vessel is lost. Camera and radar images go blanc, own-ships-symbol disappear from the ECDIS. The operator is now in the back. But for some time on he or she could extrapolate ships motions into the future.

This is where the "digital twin" comes into the picture.

3.1 *The expert-system digital twin*

As mentioned above the expert-system on the autonomous ship is the one deciding on how to move into minimum risk condition when the vessel has lost communication with the ROC. The expert-system onboard is normally constantly updated by sensors onboard, as well as with information from the ROC and from others (e.g. AIS messages from surrounding ships, information from traffic centers like a VTS, etc.). If an exact copy of the expert-system onboard are also present in the ROC and is simultaneously updated with the same information as the one onboard, the system ashore should make the same decisions as the one onboard. Now, if communication is lost and the operator loses his eyes and ears of what is going on onboard, the digital twin in the control room will for some time continue to extrapolate the situation into the future. It might even be able to catch AIS information through other vessels and coastal radio. The operator could then with probability see a simulated reality, where the digital twin demonstrates the same actions for some period of time in the ROC. Such a simulation will soon become obsolete, but a might keep the ROC operator in the loop over a short communication glitch.

Another problem is when an operator that has been attending other vessels suddenly is summoned by an unexpected alarm from one of his ships he has not been attending for some time.

4 QUICKLY GETTING INTO THE LOOP

Endsley [3] talks about Out-of-the-loop-syndrome. We know that humans are bad at monitoring well function automation. Then the human mind drifts off to more entertaining or rewarding tasks. And when then suddenly the alarm goes off, it will take some time to "get into the loop". In some situations (like in the AF477 accident above) this time may be very short. And this will happen in the ROC as well. When it happens, the operator must quickly search for the information needed for the particular emergency the alarm is about. For such situations a Quickly -getting-into-the-loop display is needed. This "QGILD" is a screen or window that opens, following an alarm activated by the expert-system requesting help from the human operator in the ROC.

In the QGILD the expert-system must collect all relevant information and display it in an uncluttered and pedagogical way so that the operator is will be informed in the shortest timespan possible. The screen must also display a timer counting down to when the operator needs to make the decision, else the expert system will take a spelled-out action.

This is of course easier said than done. The expert -system must understand the nature of the problem at each instance. It must present enough, but not too much information (information overload) to the operator. It should display possible actions in order of preference and allow the operator an easy way to select among suggested actions. Can this be done?

Let us elaborate a little on this.

4.1 The QGILD

The QGILD must fulfill the following three objectives:
1. It must give a tactical update, an at-a-glance understanding of the present situation. Showing all necessary information - but not more!
2. It should offer automation transparency, giving the operator an at-a-glance understanding of how the expert-system sees the situation, and its intentions for solving the problem.
3. Finally, it must supply tools for intervention, simple and intuitive ways for the operator to intervene and override the expert-system.

4.1.1 Tactical update

The QGUILD should provide all necessary information for tactical decision-making, i.e. decision-making in the short time span 1-10 minutes into the future. The operator should not be asked to make split second decisions – then the expert-system must take the full responsibility. Even so, this will be a challenging task as the QGILD must timely present the right information in an uncluttered and simple-to-understand way. Information overload must be avoided. This means that the expert-system must have understood that there is a problem, and it must have diagnosed the problem in the correct way in order to give the right information. If it has not realized that there is a problem, there will be no warning and no QGILD will be brought up. If the diagnose is wrong

the information displayed will not be relevant, leading to lost time.

4.1.2 Automation transparency

This objective should give the operator a quick peek into the expert-systems mind, an at-a-glance understanding of how the expert-system sees the situation, and its intentions for solving it, thus being able to judge if the system has got it right. Important to note here is that, to avoid losing time due to communication outages or an operator that is slow in responding, the expert-system could already be underway applying its preferred decision. Not waiting to the human input, but instead offer the human operator to overrule. This way we avoid that the expert-system hands the vessel over to the human who might not be in the loop - as did the flight management system on AF447, mentioned above. Important for the technical developers of the expert-system is to know that the system always has a responsibility to find a solution to any problem! It can ask the human for advice, and offer tools for intervention to override the system, but the system must always have a plan. (I acknowledge that this will never be fully possible, because of the "unknown unknowns", the black swans, that will always be there. But it should be the goal to strive for.)

4.1.3 Tools for interventions

Finally, the QGILD must offer simple-to-use tools for intervention to override the expert-systems actions. This can in a simple case be a list of possible actions, with the one the expert-system has chosen highlighted but allowing the operator to select another action. In Figure 1 is a simple example from a suggested control interface for the AutoFerry in Trondheim [8].
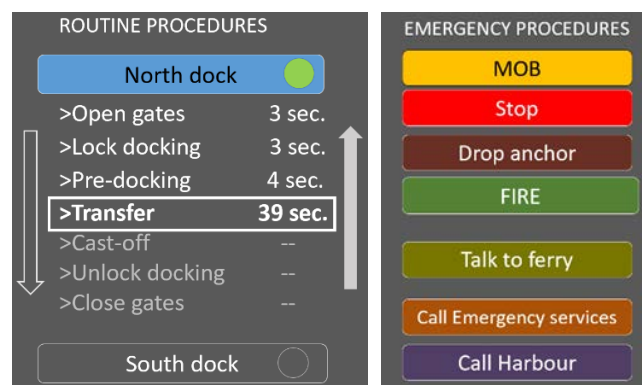

Figure 1. Example of automation transparency from a suggested control board of a small autonomous and unmanned urban passenger ferry. For details, see the text.

In the "Routine procedures" column to the left, we can peek into the expert-systems "mind" and see the different steps the automation is conducting and the time that is estimated for each step (they can also be opened to see sub-procedures). The operator can interact with each routine by clicking. We see that the ferry is underway and has 39 seconds left until the docking procedures start.

To the right is the panel for "Emergency procedures" where the operator can intervene and override the automatic transit, e.g. by "stopping" (and hoovering) or stopping (and drifting with the water current) to assist a MOB (Man Over Board).

If another boat is approaches and a close quarters situation is expected, the expert-system will switch into "autonomous control" mode, meaning that it is now acting and making decisions based on its own "intelligence", acquired experience and the rules of the road. It is illustrated in Figure 2 by a trivial example of a ship coming from starboard and thus having right of way (COLREGS Rule 15). The expert-systems decision to turn starboard and go behind the other vessel is illustrated by the green solid line (and some kind of certainty index of "98"). However, other COLREG compliant actions are shown by green dashed lines, and not-COLREG-compliant actions by yellow and red lines. The operator can override the expert-system by clicking on an action. (Or as a final resort grab the joystick and press the "manual" button.)
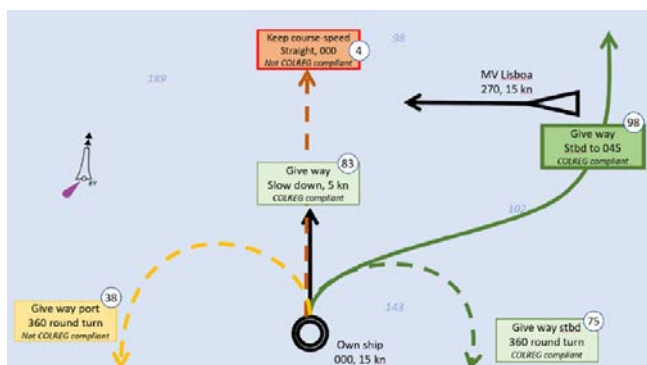

Figure 2. An example of automation transparency in a COLREG situation. For details see the text.

5 SHOULD THE COMPUTER OR THE HUMAN OPERATOR HAVE THE FINAL SAY?

A consequence of what I have stated above is that the computer always has a plan that it is executing, but the human operator is invited to override that plan.

Now, we know that a lot of accident in complex transport systems are to some extent attributed to what is called "human error". And it is true that humans make mistakes, become distracted, take short-cuts, and even fall asleep when not intending to. This is all part of the human condition. Especially for an automated future, humans are very bad at monitoring well function automation, as mentioned above.

Some of these "human error" attributed accidents involve watch officers asleep, being drunk or simply not monitoring what is going on. At the same time "the system" – the GNSS position, the ECDIS, etc. – could be very aware of that the ship is underway to beach on an island or a shoal. Should our design then allow the expert-system to prevent the human from making such a serious mistake? Who has the final say, the system or the human? The operator monitoring the automation, and the automation monitoring the human. How should the teamwork be designed? That is a very important question to think about for the

design of decision support for Remote Control Operators.

6 CONCLUCIONS

In this paper I have presented a few concepts and ideas regarding decision-support and Human-Machine Interface in the Remote Operation Centre of autonomous ships. Due to pandemic restriction during the passed year this is all desktop research and no focus groups or interviews with end users have been conducted. The concepts discussed are collection of mariners experience in the expert-system (the Artificial Intelligence), the prevalence of an updated "digital twin" of the ships expert-system in the ROC to allow as much as possible seamless situation awareness during short communication glitches. And finally the launching of a Quickly-getting-into-the-loop display to help the operator achieve situation awareness during alarm situations.

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