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ICMASS 2018

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Editors:
Kwangil Lee and Ørnulf Jan Rødseth

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PREFACE

These proceedings contain selected papers from the first International Conference on Maritime Autonomous Surface Ships (ICMASS), held in Busan, Republic of Korea, on November 8th and 9th, 2018. The first day of the conference had ten invited presentations from the international autonomous ship community, while the second day contained parallel sessions on industrial and academic topics respectively. A total of 20 industrial and 16 academic presentations were given. From the presentations, six full manuscripts are presented in these proceedings after peer review by two Korean and Norwegian experts.

ICMASS is an initiative from the International Network for Autonomous Ships (INAS, see http://www.autonomous-ship.org/index.html), an informal coalition of organizations and persons interested in autonomous ship technology. In 2018 it was organized by KAUS – Korea Autonomous Unmanned Ship Forum. The plan is to make this a yearly event in different places around the world. In 2019 it will take place in Trondheim, arranged by SINTEF Ocean AS and NTNU in cooperation with the Norwegian Forum for Autonomous Ships (NFAS).

The organizing committee would like to thank everyone who has helped with review of manuscripts, all those who helped to promote the conference and all authors who have submitted and presented their contributions.

Kwangil Lee & Ørnulf Jan Rødseth

KAUS Korea Autonomos and Unmanned Ship Forum

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INTERACTION BETWEEN MANNED AND AUTONOMOUS SHIPS: AUTOMATION TRANSPARENCY

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Abstract

Maritime Autonomous Surface Ships (MASS) is on the research agenda of several countries. In Norway a 120 TEU autonomous container feeder is currently being built. Hopes are attached to safety as well as costs and efficiency benefits. The explicit assumption is that with no humans on the bridge "human error" will go away. However, great challenges will be found in the interaction between MASS and humans on the bridges of other SOLAS and non-SOLAS vessels. An unanswered question is whether a MASS should transmit that she is in autonomous mode or if she should remain anonymous, just as any other ship? This discussion paper argues for the first alternative. Arguments are also given for "automation transparency," methods allowing other seafarers to "look into the mind" of the autonomous ship, to see if they themselves are detected and what is the present intentions of the MASS.

Keywords: *MASS, autonomous ships, automation transparency, route exchange*

Figure 1**.** The Photomontage of the planned *YARA Birkeland* autonomous container vessel passing the Brevik sound in southern Norway. To the right is the tower of Brevik VTS. (Image by the author.)

1. Introduction

Large autonomous merchant vessels are still not for real. However, they are on the drawing board in several places and in Norway the building contract is already signed for YARA Birkeland, the first Maritime Autonomous, Surface Ship (MASS) container feeder, planned to start tests runs in 2020 [1]. In the absence of international regulations from the IMO, prototype testing will have to commence in national waters, which in the Norwegian case means inshore archipelago navigation with narrow channels in a busy industrial area with gas carriers and vessels with other hazardous cargo and, summertime, with large numbers of small leisure crafts. The area is covered by the Brevik VTS which in 2015 made 623 interventions [2]. The challenge will be to detect, identify and in some cases decide or negotiate a change of action for all these targets.

The project is ambitious, the 80 meters long, unmanned, autonomous vessel, taking 120 containers with a fully electric propulsion system, will replace some 40,000 truck-journeys every year. Thus moving heavy traffic from road to sea, from fossil fuel to hydro generated electricity. The plan is currently that she will start tests in 2020. First with a manned bridge onboard, then with the same bridge lifted off to the quay side remotely controlling the vessel, before finally attempting to go autonomously in 2022 [1].

The technological challenge is of course a major driver for a project like this (subsidized by the Norwegian government) but the environmental benefits (offloading heavy traffic from narrow roads, and switching fossil fuel for electric) are also important, and maybe the most important in the long run. With just one ship planned and in this limited setting the savings on personal (switching lorry drivers for service personal ashore) will be limited, if any.

The safety case, often referred to as the major driver, exchanging "human error" for safe automation, remains

to be proven. So far in history, ship automation has shown great safety benefits, for instance reducing the global number of total hull losses from 225 in the year 1980, to 150 in 1996 and 33 in 2016 (ships over 500 gross tons, total losses as reported in Lloyds List) [3]. However, moving from todays supervised automation to the automation levels of tomorrow will be a major paradigm shift.

2. Unmanned, automatic and autonomous

Ships today are already transiting automatically. With an autopilot in track-following mode, set so that the ship can execute turns with a preset radius without acknowledgment from the officer of the watch, the ship can transit from A to B without support - given that the route planning is correct - because the ship is only following a pre-planned route. What is needed to remove the operator from the bridge is different sensors that can detect moving and uncharted obstacles in the sea and anti-collision algorithms based on the International Regulations for Preventing Collisions at Sea (COLREG's) [4].

However, as long as this system does not involve higher degrees of machine learning it will need to be pre-programmed and "black swans" are bound to appear. ("Black swans," unforeseen situations which the programmers have not anticipated, "unknown unknowns".)

Furthermore, an automatic ship does not have to be unmanned. It can have a partly manned bridge ("constrained autonomy" in IMO terms). As the level of automation increases, it might allow the Officer of the Watch (OOW) to take a short power nap during an uneventful crossing, handing over the watch to the automation, relying on that the automation will wake the OOW up in case of anything happens. The watch can also be handed over to a Shore Control Centre that can access the ships sensors and communication, ready to wake up the OOW if something unexpected happens. In this case the ship is still in manual mode, however, remotely monitored). The next step would be to grant the shore centre access to the autopilot, in which case the ship will be remote controlled. It is reasonable to think that this will be a gradual evolution towards higher and higher levels of automation. At a time, we might imagine ships with the captain onboard but the officer of the watch on the bridge is an AI system. However, the captain is there to supervise and intervene – once he has climbed from his cabin to the bridge. Is this an autonomous ship?

It can also be useful to consider the concept "Operational Design Domain" (ODD) used by the self-driving car industry [5]. In the maritime domain, it would mean that there will be certain shipping lanes and fairways were the automation has been specifically trained and which have been specifically prepared, maybe with designated lanes, or by specific technical infrastructure. In these areas, a ship may navigate automatically, while the ship in other areas must navigate manually with a manned bridge or remote controlled from the shore.

For the discussion here the level of autonomy or staffing might not be so interesting as whether the ship is in "autonomous mode" or not. If automation is navigating and taking decisions or if humans are, regardless of whether the captain is in his cabin onboard or in a remote centre ashore. Or does it matter? Maybe the only crucial point is whether the ship follows the COLREGs or not?

A ship would be in "autonomous mode" if the automation "has the con," navigating and doing collision avoidance automatically, wherever there are navigators onboard or not.

3. The COLREG's

There is a difference between humans and machines: machines do as they are programmed; with humans you never really know. They might even have gone to bed. In many maritime accidents, the wheelhouse was found empty, as in two stranding's in Sweden the summer 2018 [6, 7]. It could then be comforting to know that autonomous ships are always awake and vigilant and that they always follow the COLREG's.

However, COLREG's can be ambiguous. Just to give an example the required actions are different for two ships in a crossing situation in fog (rule 19) and in good visibility (rule 15), as it also is in an overtaking situation (rule 19 vs. rule 13). The tricky part is to determine when the visibility is restricted [8]. Discussing the potential ambiguities of the COLREG's is out of the scope of this paper. However, humans interpret rules differently, as there is an abundancy of examples of in accident reports. The question is if MASS will do better. The question is if humans on other vessels will trust the automation – and how the automation will behave when humans do not follow the rules. This is when automation transparency might show to be crucial.

4. Automation transparency

Every one of us that are struggling with the complexity of digital tools know that they do not always do what we want or assume they will do. They "think" different from us. An innate tendency of human psychology is to attribute human traits, emotions, or intentions to non-human entities. This is called anthropomorphism. We do so because it gives us a simple (but faulty) method to understand machines. It is likely that this will also be applicable to MASS. We will assume that they will behave as if they had human on the bridge.

The assumption is that if MASS follow COLREGs its behavior will be a 100 % predictive. However, this is given that the spectrometers onboard interpret the visibility the same way you and I do, and that the intentions of other manned or unmanned ships are interpreted rightly by the AI. An old accident in the English Channel can serve as an example of COLREG's and misinterpreted intentions.

A foggy night in 1979 the French ferry *St Germain*, collided with the bulk carrier Adarte in the English Channel. *St Germain* was coming from Dunkirk in France, destined across the Channel to Dover in the UK. As she was approaching the Dover Strait Traffic Separation Scheme (TTS), she started to turn slowly to port, away from the strait course to Dover, intending to run SW in the inshore traffic zone, down the outside of the TTS in order to find a clearer place to cross the TSS at a right angle (according to rule 10). At the same time the *Adarte* was heading NE, n the NE bound lane of the

TSS. The pilot onboard saw the radar target of *St Germain* and assumed, quite wrongly, that she would cross ahead of him. The pilot made a series of small course alternations to starboard to allow her to cross ahead (giving way for a ship from the starboard side according to rule 15, but not following rule 16 which talks about taking "substantial action"). But instead of continuing her strait course *St Germain* continued her port turn and the two ships collided. *St Germain* sank killing a number of passengers [9].

This accident is retold to illustrate the need to understand intentions. The officers on the bridge of *Adarte* did not understand that the intentions of *St Germain* was not to cross the TTS just yet. The officers on the bridge of *St Germain*, following an accustomed behavior, did not see that their maneuver could be misunderstood from the *Adarte*. The problem would remain if one or both of the ships were autonomous.

Intention sharing among traditional ships, route exchange, has been investigated within the realms of the IMO concept e-Navigation for several years and we will not go deeper into that here apart from how this can be used for MASS.

Automation can share information about its working, its situation awareness and its intentions. Answers to questions like: What is the intention of the MASS? What does the automation know about its surroundings? What other vessels that has been observed by its sensors? could be answered e.g. by a live chart screen accessible on-line through a web portal by other vessels, VTS, coastguard etc. An example of such shared situation awareness screen is showed in Figure 2.

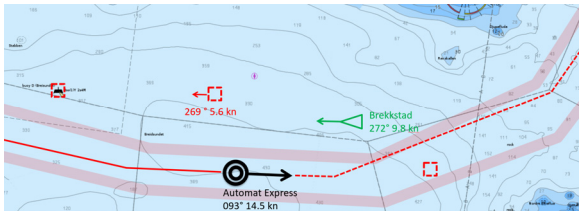

Figure 2**.** An on-line chart showing the situation awareness of the autonomous ship, where it think it is, what other ships and objects it has observed, and what intentions it has for the close future.

Based on the situation awareness provided by chart and sensors the automation will make decisions on how to interprets the COLREG's. It would then be a safety benefit if these decisions could be communicated to other ships, as argued in [10]. However, there is a difference between the equipment of large SOLAS ships and smaller non-SOLAS vessels when it comes to the ability to receive such communications.

4.1 SOLAS ships

Large ships obey under IMO's SOLAS convention. A SOLAS ship (as defined in Maritime Rule Part 21) is any ship to which the International Convention for the Safety of Life at Sea 1974 applies; namely: any passenger ship engaged on an international voyage, or a non-passenger ship of 500 tons gross tonnage or more engaged on an international voyage [11].

SOLAS ships must transmit their position and some other information using AIS (Automatic Identification System). In addition, SOLAS ships are usually big and make good radar targets, which will provide a second source of information. Furthermore, all SOLAS ship must make a voyage plan from port to port. As mentioned several passed and ongoing projects aim at collecting route plans and coordinating ship traffic for reasons of safety and efficiency (e.g. EfficienSea, ACCSEAS, MONALISA, SMART navigation, SESAME, and the STM Validation projects). These attempts in route exchange would make it possible for SOLAS ships – also MASS - to coordinate their voyages and show intentions well ahead of time to avoid entering into a close-quarters situation where the COLREGs will apply.

Route exchange would for instance allow each ship to send a number of waypoints ahead of the ships present position though AIS to all ships within radio range. All ships can then see other ships intended route. In the ACCSEAS project 2014 a simulator study was made with 11 professional British, Swedish and Danish bridge officers, harbor masters, pilots and VTS operators with experience from complex traffic in the test area which was the Humber Estuary. The feedback from the participants on the benefits of showing intentions were overall positive [10]. Figure 3 shows a screen shot of the test ECDIS.

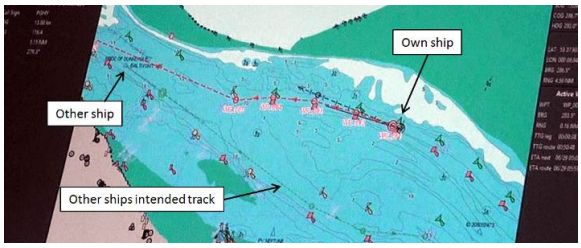

Figure 3**.** A screen shot from the test ECDIS showing the own inbound ship to the right. Another, outbound ship is to the far left and the question is whether this ship will take the northern or the southern route. By clicking on the ship the intended route (the southern fairway) is shown and problem solved [10].

However, for small, Non-SOLAS vessels, the situation is different.

4.2 Non-SOLAS vessels

The challenge will be greater when we look on smaller, non-SOLAS vessels: small fishing boats, leisure crafts, sailing yachts, motor boats all the way down to kayaks. For these craft there is no mandatory carriage requirement of sophisticated electronic communication equipment. In Scandinavian waters, this kind of vessels often stay close to the coast or inside the archipelago, and will therefore stay out of the way of commercial deep-water traffic. But in the case of the short sea shipping, they will be of real concern.

First, there is the question of detection. Non-SOLAS vessels are not required to have AIS. It is the sensors of the MASS that must detect, identify any small craft.

The human lookout on a manned vessel will on the MASS be replaced by different sensor systems, both daylight and heat sensitive infrared night vision cameras. Then, computer vision algorithms will be used to extract information from these images to try to isolate single objects like boats and buoys. These algorithms will be supported by radar, and maybe LIDAR on short distances up to 100 meters. The challenge here will still be to detect small objects and infer their course and speed. Low visibility in fog, snow, rain and high waves will add to the difficulty. And here we have the problem of automation transparency. Maybe the person in a small fishing boat, leisure craft or kayak, do not trust the MASS with the sole responsibility for detection and avoidance manoeuvre. Maybe he or she will want to know whether or not the autonomous ship observed him or her. How could a MASS communicate intentions to a small craft not equipped will the technology of larger SOLAS ships?

4.3 Some examples of automation transparency for non-SOLAS vessels

As a pedestrian or bicyclist, crossing a street in front of a car that has stopped, you need to make sure that the driver has seen you. You do that by seeking eye contact. If the driver is looking at you, you might assume that an understanding has been negotiated and you can safely cross. (This is a problem that remains to be solved for autonomous car industry.) The situation is more complicated at sea. One solution would be if you got a positive signal when looking at a ship, indicating that that ship has detected you. For instance, a green light meaning that you have been spotted. But of course then that light should only be visible for you and nobody else, which might raise some technical challenges as there might be many boats in the area and each one would need to see s similar green light. If you were not detected the signal would show red (as illustrated in Figure 4).

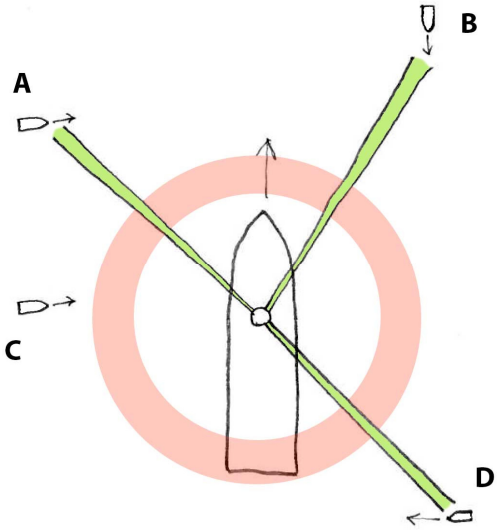

Figure 4. Example of automation transparency: A simplified illustration of an app for autonomous ship communication. Left the image shows the crosshairs of the camera view. Aim at the oncoming ship and press “Acquire”. Middle, the answer is received: you are “present” on the chart of the autonomous vessel (and can connect a phone call to the remote control centre). Right, you are not “present” on the chart of the autonomous vessel, but can report you name, position, course and speed.

A good thing with such a solution is that it would not require any equipment on the side of the small craft.

Another, maybe technically simpler solution, would be using smartphones already available in the pocket of most people. All smartphones have a satellite based navigation (GNSS) receiver, which with relatively good accuracy can provide a position. Assuming GSM coverage in an archipelago, this position can be sent to an approaching vessel.

Let us imagine the following scenario: You are fishing in, or crossing, a large fairway in the archipelago. Far off a MASS is approaching. You can see it is in autonomous mode because of its MASS signal (this could e.g. be a purple flashing light/flag – purple is an unused color in COLRE’s). You may also see on your navigational chart that you are in an area with MASS traffic. Should you continue crossing the fairway or wait? Or, if you are fishing, should you stay or move out of the way? Has the MASS even seen you?

In this hypothetical scenario your first step would be to take up your smartphone and start the Autonomous Ship Communication App. The interface show the camera view with crosshairs in the middle and the prompt “Aim at the ship” (see Figure 5).

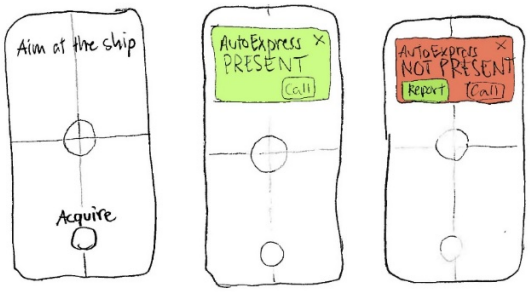

Figure 5. Example of automation transparency: A simplified illustration of an app for autonomous ship communication. Left the image shows the crosshairs of the camera view. Aim at the oncoming ship and press “Acquire”. Middle, the answer is received: you are “present” on the chart of the autonomous vessel (and can connect a phone call to the remote control centre). Right, you are not “present” on the chart of the autonomous vessel, but can report you name, position, course and speed.

You then aim the crosshairs at the oncoming ship and click “Acquire”. An image of the ship appears with the prompt “Do you want to ask if the Autonomous Express has seen you?” and an OK button.

You click the OK button and wait for an answer.

A few seconds later the answer arrives: “Yes, S/Y Matilde, I have observed you and you are present on my chart. Current course and speed is OK” Or maybe “Thank you for identifying yourself, S/Y Matilde, I have added you to my chart. Please wait until I have passed.” (see Figure 5).

4.4 What is your intention?

The short-term intentions of the autonomous ship could be shown on a chart view in a web portal or in the app, as mentioned above, but it could also be shown in a signaling mast together with the sign mentioned above. Such a mast could for instance consist of three vertical lights as shown in Figure 6, left.

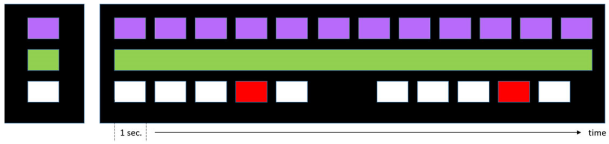

Figure 6. Example of automation transparency: Left, the three self-driving mode signals. One over the other. Right, a time diagram of the flash sequences described in detail in the text.

4.4.1. The top light

The top light should a purple identification light for vessels navigation in autonomous mode. The light must be easy to spot and unique. Some other designated color or character could be used instead.

4.4.2. The middle light

The middle light would be the green or red "your-presence-is-spotted" light mentioned above. It would then show green for vessels known to the automation, and red for "unknown" vessels. In Fig. 6, left, the middle signal show green because my boat has been observed from the ship. The light is static because my course and speed is OK and is not inflicting with the navigation of the autonomous ship. If I need to give way, the green light could be blinking.

4.4.3. The bottom light.

The bottom light could be a signal showing the intentions of the MASS for the next 5 minutes. The light could consist of e.g. 5 flashes, one for each minute into the future. A white flash would mean "I will continue my course straight ahead". A red flash "I am turning port" and a green flash "I am turning starboard". In the sequence illustrated in the temporal diagram in Fig. 6, right, the bottom light shows 3 white flashes "I will continue my course straight ahead for the next 3 minutes". Then followed by a red flash, meaning, "in the 4th minute I will make a port turn", and finally a 5th, white flash, meaning, "I will then continue on this new course during the 5th minute". Of course a port or starboard turn could be of different sizes and take different long times to execute, and maybe one could find more detailed codes for this, or just keep the signal simple and general.

A daylight version of the signals could follow the same pattern using very strong light or LCD boards facing all four directions.

The benefit of such a signaling scheme would be that there is no need for any technological communication equipment to read the intentions of the MASS, or for a kayaker to bring up a smartphone at the same time as he is paddling and balancing his kayak. On the other hand, the signals described above are quite complex (apart from the technical challenge in the "I-have-spotted-you light) and might be difficult for laymen to learn, as indeed are the many light character of common lighthouses.

5. Conclusions

I have in this discussion paper pointed at some communication challenges regarding the interaction between autonomous, unmanned ships and manned ships and crafts of different sizes.

I have also pointed to some possible solutions based on automation transparency, meaning that the automation of the MASSs transparently shares their situation awareness and decision-making with other vessels and authorities like VTS and coastguard.

I have also given some concrete examples of what such automation transparency can look like. Many other solutions are also possible. And nothing prevents the same communication techniques to be used also in the interaction between manned SOLAS vessels and small non-SOLAS vessels.

Acknowledgements

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