Safety of autonomous shipping: COLREGS and interaction between manned and unmanned ships

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Autonomous, unmanned ships is on the research agenda in many countries. In 2018 the International Maritime Organization (IMO) added Maritime Autonomous Surface Ships (MASS) to its agenda and started a scoping exercise to find out how the MASS concept would fit into prevailing regulations and conventions. One of the most important international conventions is the rules of the road, the Regulations for Preventing Collisions at Sea, COLREGS for short. These rules are expressed in qualitative terms. The question is whether automatic collision avoidance algorithms will be able to safely interpret words like "early" and "substantial", or if COLREGS needs to be amended with quantitative specifications? This paper discusses interaction between automatic ships and traditional manned ships in the light of prevailing regulations and new e-Navigation solutions suggested. The paper concludes first, that ship traffic management concepts like "route exchange" and transmission of "intended routes" can be used to coordinate traffic and avoid ships entering into close quarters situations where COLREGS apply. Finally, the concept of "automation transparency" is discussed and a number of concrete examples are suggested.

Keywords: Autonomous ships, unmanned ships, maritime autonomous surface ships, MASS, COLREGS, IMO.

1. Introduction

Large autonomous merchant vessels are still not for real. However, in Norway the building contract is already signed for *YARA Birkeland*, the first Maritime Autonomous, Surface Ship (MASS), an unmanned container feeder scheduled to start tests in 2020 (Kongsberg, 2019). Lacking IMO regulations, the tests will have to commence in national waters, which in this case means the Grenland area of Porsgunn and Larvik in southern Norway with complex narrow, inshore archipelago navigation. It is a busy industrial area where a large portion of the ship traffic consists of gas carriers and vessels with hazardous cargo and, summertime, an abundance of small leisure crafts and kayaks. The sea traffic in the area is monitored by the Brevik VTS which in 2015 made 623 "interventions," meaning that the VTS asked for some alteration from the planned sailing route (Statistics Norway, 2016). Conducting autonomous navigation in such an area is a huge challenge.

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 hauls 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 test runs 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 (Kongsberg, 2019).

1.1 *Unmanned, automatic and autonomous*

Today's manned ships may be thought of as "manual." However, the level of automation is in many ships today quite high. With an autopilot in "track-following" mode, set so that the ship can execute turns along a preplanned route without acknowledgment from the Officer of the Watch (OOW) - given that the voyage plan is correct and validated for a set under-keel-clearance. This is the way the Norwegian coastal express Hurtigruten navigates during most of its in-shore route from Bergen to Kirkenes (Porathe, pers. comm.). But the OOW still must be present on the bridge to look out for and handle encounters with other ships and crafts. What is needed to remove the operator completely is different sensors that can see and identify moving, uncharted obstacles in the sea, and an autopilot connected with a collision avoidance module programmed according to the International Regulations for Preventing Collisions at Sea, COLREGS (IMO, 1972). With such a system it is speculated that a ship in autonomous mode may navigate automatically.

The focus in this discussion paper is on how the automation handles interaction with other ships, and particularly how it follows the rules of the road, the COLREGS.

2. The COLREGS

One may ask if maybe new rules are needed for autonomous ships? Or maybe there should be machine-to-machine negotiations in every individual case of conflicting courses? The final answer to

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that question is unknown, but it is likely that as long as MASS will interact with humans on manned ships there has to be a limited number of common and easy to understand rules known to, and obeyed by, all vessels at sea. One can dream up other rules, but what we got, and presently need to adhere to, is the COLREGS.

Some rules will however cause problems, and I will touch upon some of them in the following.

2.1 *Rule 2: the ordinary practice of seamen*

Rule 2 of the COLREGS is about responsibility. It has two sections. Section (a) state "Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precautions which may be required by the ordinary practice of seamen, or by the special circumstances of the case."

Section (b) of the same rule states that "In construing and complying with these Rules due regard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these Rules necessary to avoid immediate danger."

What this rule basically says is that you must always follow these rules, but that you must also deviate from these rules when necessary to avoid an accident. In essence, if there is an accident it is a good chance that you have violated one or both of these sections. The problem for the navigator is how long, or close into an encounter, he or she should follow the Rules and when it is time to skip the rules and do whatever is necessary to avoid a collision. The answer is: it depends on the circumstances. The Rules give no hint as to the number of cables or miles, minutes or seconds. It does not even try to define the "ordinary practice of seamen." The same goes for Rule 8 which talks about "good seamanship".

Similar soft enumerations are found for instance in Rules 15, 16 and 17.

2.2 *Rule 15 to 17, risk of collision*

Rule 15 of the COLREGS talks about "crossing situations": "When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel."

Calculating when a crossing situation may lead to a collision is pretty straightforward given that present course and speed can be extrapolated. If the bearing to the other ship is constant over time, it can be assumed that there exists a risk of collision. (This is, however, in reality not always the case as the intentions of the other ship may not be known.)

Rule 15 also defines which vessel should take action to avoid collision. "The one which has the other on her own starboard side."

The following rule then defines how this action should be done by the "give-way" vessel (Rule 16): "Every vessel which is directed to keep out of the way of another vessel shall, as far as possible, take early and substantial action to keep well clear."

This "action" could be a change of speed or a change of course, but for the software programmer the problematic keywords here are "early and substantial." There is no suggestion in miles or minutes what constitutes "early," neither how large course change or speed change constitutes "substantial."

Rule 17 then, defines the actions of the ship that is not obliged to yield, the "stand-on" vessel: "(a), (i) Where one of two vessels is to keep out of the way the other shall keep her course and speed. (ii) The latter vessel may, however, take action to avoid collision by her maneuver alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these Rules. (b) When, from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision. (c) A power-driven vessel which takes action in a crossing situation in accordance with subparagraph (a)(ii) of this Rule to avoid collision with another power-driven vessel shall, if the circumstances at the case admit, not alter course to port for a vessel on her own port side. (d) This Rule does not relieve the give-way vessel of her obligation to keep out of the way."

This rule adds to the complexity by using qualitative definitions like "as soon as it becomes apparent," "finds herself so close that collision cannot be avoided by the action of the give-way vessel alone," "action as will best aid to avoid collision" and "if the circumstances at the case admit."

For a programmer programming the collision avoidance module of an autonomous navigation software the difficulty is not only in judging which action, but also, as already mentioned, when to execute it "early" and "substantially". The answer will be the same as it was in the previous section: it depends on the circumstances. Are there only two ships meeting alone on the high seas the task might be relatively simple, but at the other end of the spectrum, in a high complexity situation, e.g. in a constrained and intensely trafficked area like the Straits of Malacca and Singapore, the task is of an entirely different dimension. Not only does the large number of ships in a limited space change the value of variables like “early” and “substantial,” but an evasive maneuver for one ship may lead into a close quarters situation with another ship and so on, in a cascading interaction effect with unpredictable results. Figure 1 shows the complicated traffic situation around Skagen on the northern tip of Denmark on an ordinary day.

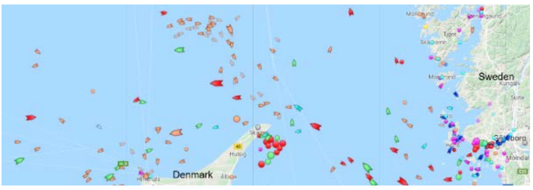

Fig. 1. This was the traffic situation at Skagen, the northern tip of Denmark at 15:00 on 5 November 2018. One may reflect on the difficulties of COLREG algorithms needed to do collision avoidance in such an area where giving way to one ship might lead into another conflict situation in an unpredictable, cascading manner (screen shot from MarineTraffic.com).

In some areas there can also be a different culture of how things are done (sometimes quite contrary to COLREGS). When the high speed ferry Stena Carisma trafficked the Gothenburg-Fredrikshavn line in 30+ knots a number of years ago, an officer I spoke to said “We always keep out of the way of everything that moves because we are so fast and maneuverable” (Porathe, pers. comm.). Also, in the Sound between Sweden and Denmark, the Helsingborg-Helsingor ferries has a culture of keeping out of the way in most situations (Porathe, pers. comm.).

A possible strategy for programmers trying to catch “early and substantial” as well as “the ordinary practice of seamen” could be to study large amounts of AIS (Automatic Identification System) data for the specific area in questions and from that data deduce typical behavior and numerical attributes of “early” and “substantial action”. A useful concept could then be ships “safety zones” which is the zone around one’s ship that a navigator tend not to let other ships within. “A zone around a vessel within which all other vessels should remain clear unless authorized,” (IALA, 2008). This zone tends to be larger on the open sea than in narrow waters or in a port and can be studied using AIS data. Using such AIS studies, establishment of a zone outside which an action can be considered “early” could be attempted. But the context is important, not only the static geographical context, but also the time dependent traffic density context.

The Nautical Institute tries to set some quantitative figures on when “early” could be when they suggest the closest distance another ship should be let: “As a general guideline, attempt to achieve a CPA [closest point of approach, authors addition] of 2 [nautical, ibid] miles in the open sea and 1 mile in restricted waters.” (Lee & Parker, 2007, p. 35).

If all ships in such a complex situation where autonomous and governed by clever algorithms there is a chance that such a collision avoidance application could be successful, but in a mixed situation where most or many of the ships are controlled by humans, which are less predictable, the risk of a bad outcome is evident.

2.4 *Rule 19, restricted visibility*

The final rule that I want to bring up here is Rule 19, “Conduct of vessels in restricted visibility.” This is a quit lengthy rule which says:

“(a) This Rule applies to vessels not in sight of one another when navigating in or near an area of restricted visibility.”

Further “(b) Every vessel shall proceed at a safe speed adapted to the prevailing circumstances and conditions of restricted visibility. A power-driven vessel shall have her engines ready for immediate maneuver.”

“(c) Every vessel shall have due regard to the prevailing circumstances and conditions of restricted visibility when complying with the Rules of Section I of this Part.”

“(d) A vessel which detects by radar alone the presence of another vessel shall determine if a close-quarters situation is developing and/or risk of collision exists. If so, she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided: (i) an alteration of course to port for a vessel forwards of the beam, other than for a vessel being overtaken; (ii) an alteration of course towards a vessel abeam or abaft the beam.”

“(e) Except where it has been determined that a risk of collision does not exist, every vessel which hears apparently forwards of her beam the fog signal of another vessel, or which cannot avoid a close-quarters situation with another vessel forwards of her beam, shall reduce her speed to the minimum at which she can be kept on her course. She shall if necessary take all her way off and in any event navigate with extreme caution until danger of collision is over.”

The Dutch Council of Transportation has added an amplification to this rule for Dutch mariners: “During a period of reduced visibility unexpected behavior of other vessels should be anticipated. The speed and the correlated stopping distance must correspond with this situation” (van Dokkum, 2016).

The big difference with this rule versus Rule 15 above is that in restricted visibility both vessels are suddenly give-way vessels and the responsibility for avoiding a collision is shared.

The problems here for a quantitative approach lies in soft enumerations like “safe speed,” “due regard to the prevailing circumstances and conditions of restricted visibility” and “take avoiding action in ample time.” But also in the problem of defining “restricted visibility.” As a meteorological phenomenon “restricted” is not defined, nor is “safe speed”, although an assumption might be that the vessel should be able to stop within the distance that can be overlooked. An assumption that cannot always be followed as in many parts of the world ships regularly navigate in conditions of visibility where even the own ships forecastle (front) cannot be seen from the bridge.

Another reflection is that “restricted visibility” refers to human visibility of the eye, which in the autonomous case can be translated to the visibility of the day-light cameras. Section (d) in Rule 19 which refers to when ships are detected “by radar alone” was added in 1960 after a number of “radar assisted accidents” (the most well-known was the Stockholm-Andrea Doria accident in 1956). An autonomous vessel will most probably, apart from day-light cameras, AIS and radar, also have infrared cameras and maybe short-range LIDAR. But even if sensor resources on an autonomous ship could be judged as being better than the human look-out, this rule makes it necessary to include visibility sensors to decide if Rule 19, “restricted visibility,” or the rules 11 to 18, “conduct of vessels in sight of each other,” should apply. A confounding factor here, that needs to be taken into consideration, is that fog often appears in patches or banks, so even if your own ship may be in an area of good visibility, the other vessel might be hidden in a fog bank, in which case Rule 19 apply. A possible solution for the MASS might be to compare radar and camera images.

A phenomenon worth taken into consideration is that while an autonomous vessel will weigh its different sensor inputs in an objective manner resulting in a sighting with a probability measure, the human operator on a manual vessel has a cognitive system that prefer visual egocentric input through the eyes as compared to exocentric images from radar and electronic charts that needs to be mentally rotated to be added to the inner mental map, (Porathe, 2006). An example of this is the allision of the container vessel Cosco Busan in 2007 with the San Francisco Oakland Bay Bridge in heavy fog but with fully working radar and GNSS/AIS support, (NTSB, 2009).

The human cognitive system has other limitations such as e.g. “normality bias” and “confirmation bias.” (Porathe et al., 2018). With this, together with other human shortcomings like fatigue, an inclination towards short-cuts, and sometimes sheer violations, the risk is that the list of potential interaction problems between human and machine guided navigation will be long.

3. Quantitative COLREGS

The code for a collision avoidance software that is to cover for all possible situations will have to be very long and it would still not suffice. The unknown unknowns, “black swans”, would keep appearing because of the “special circumstances of the case” (rule 15).

From a computer programmer’s point of view, it would certainly be helpful if all qualitative, soft, enumerations of COLREGS could be quantified into nautical miles, degrees of arc and clock minutes once and for all. This would greatly facilitate the development of the necessary algorithms that will govern future collision avoidance systems. However, such a quantified regulatory text would, in the same way, have to be very lengthy and it would still not cover all possible situations. Instead COLREGS, like other legal text has a general format that is open to interpretations in a court of maritime law, and the opposite of “the ordinary practice of seamen,” i.e. “good seamanship,” include juridical options such as “negligence” and “gross negligence”, (van Dokkum, 2016). Ships’ technical performance and maneuverability, experience and training of seamen, all evolve with time and for the rules of the road to be valid they must allow for such evolution and thus be written in a open, general manner.

So instead of changing COLREGS it is my opinion that it is the algorithms of collision avoidance applications that need to go those (several) extra miles to be precise and quantitative. By using AIS data and large-scale simulations, applications can be made to learn the most effective and efficient way of maneuvering in different situations, still following the COLREGS. It would probably be beneficial if such machine learning was ongoing “lifelong” for the AI (Artificial Intelligence) on the bridge, which then would become more and more experienced through the years. However, it is unlikely that the IMO would accept an AI on the bridge which was not certified and who behaved in a precisely predetermined way for a specific situation (even if this could be defended by comparing the AI to a trained and licensed third mate working his way up through the ranks gaining more and more experience).

Another point to pay attention to is that, as long as there are manual ships governed by humans on the sea, the actions of autonomous ships has to be predictable and understood by these humans. Autonomous navigation, supported by artificial intelligence on the bridge, has a number of advantages compared to human, manual navigation: improved vigilance, improved sen-sing and perception, longer endurance, an ability to look further into the future and to keep more alternative options open during the decision-making process. For instance, by keeping track of all ship movements on a very long range an AI might be able to predict a possible close quarters situation long ahead of a human navigator - but may therefore make maneuvers which might not make sense to an OOW on a manual ship in the vicinity. Therefore, it is of outmost importance that autonomous ships are predictable and transparent to humans.

4. Automation transparency

Automation transparency is about how the automation communicates with humans, to ensure mutual understanding and promote good teamwork.

4.1 *Anthropomorphism*

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" differently 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. However, the chance is that if we know that MASS always will follow COLREGS, we can learn to know their behavior and in a human manner be able to understand their workings. As opposed to normal, manned ships, where you always have to be cautious of misunderstandings or violations.

4.2 *Identification light*

It is therefore suggested that ships that navigate in autonomous mode in the future will show some kind of identification signal. It could e.g. be an "A" added to their AIS icon in ECDIS or on the radar screen (as in Figure 3). During dark it could be a light signal, e.g. a purple mast-head all-around light as shown in Figure 2.

Fig.2: Should ships navigating in autonomous mode carry a special identification light? The behavior of the navigation AI maybe different from the behavior of normal, manned ships. The light could be purple which is a color that is not used for other purposes. The same discussion and color choice is debated in the autonomous car industry.

The assumption above is that if autonomous ships always follow COLREGS their behavior will be a hundred percent predictable. But as we have seen above, this might not be true if e.g. the spectrometers onboard the autonomous ship does not interpret "restricted visibility" the same way we do (and therefore Rule 19 should or should not be used).

4.2 *Intentions*

Another important issue is understanding intentions. Interpreting the intentions of other ships correctly is imperative to rule-following. An old accident in the English Channel 1972 can serve as an example of what misinterpreted intentions (and therefore applying the wrong rules) may lead to:

The ferry *St. Germain*, coming from Dunkirk in France and destined for Dover, was turning slowly to port, away from the strait westerly course to Dover. Instead her captain intended to take her south-west, down on the outside of the Traffic Separation Scheme (TSS), in the Inshore Zone, in order to find a place when the traffic had cleared to cross the TSS at a "right angle" according to Rule 10 of the COLREGS. The bulk carrier *Adarte* was heading northeast up the TSS to-wards the North Sea. The pilot onboard recognized the radar target as the Dunkirk-Dover ferry and assumed, quite wrongly, that she would cross ahead of him and that there now existed a risk of collision (Rule 15). *Adarte* would then be the give-way ship and was obliged to give-way by turning to starboard. At the same time that *St. Germain* started her port turn, the pilot on *Adarte* started to make a series of small course alternations to starboard to give way (quite contrary to the "substantial action" required by Rule 16). *St. Germain* did not notice this and continued her port turn and the two ships collided. *St. Germain* sank, killing several passengers (Lee & Parker, 2007).

This accident is retold to illustrate the need to understand intentions and this goes for both manned and unmanned ships. If the intention of the other ship is not understood, the risk is that COLREG will not save a situation. It is therefore important that the navigation AI share information about its workings, its situation awareness and its intentions. Questions like: What does the autonomous ship know about its surroundings? What other vessels has been observed by its sensors? These questions could be answered by e.g. a live chart screen accessible on-line through a web portal by other vessels, VTS, coastguard etc. See Figure 3.

Based on its situation awareness the automation will make decisions on how it interprets the COLREGS. It would be a benefit if the intentions of ships could be communicated, as argued in, Porathe & Brodje (2015).

Large ships must transmit their position and some other information using AIS. In addition, large ships are usually good radar targets, which will provide a second source of information. Furthermore, all large ships must make a voyage plan from port to port. Several passed and on-

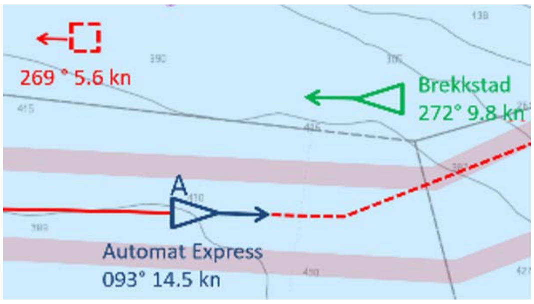

Fig.3: This image shows example on how the AIS symbol in electronic charts can be augmented with the letter “A” for ships presently navigating in “autonomous mode”. The image is also an example of an on-line web portal which visualizes the “situation awareness” of an autonomous vessel. Logging on to “Automat Express” reveals that she has detected the AIS of Brekkstad, and an unidentified echo on her port quarter.

going projects aim at collecting route plans and coordinating ship traffic for reasons of safety and efficiency (e.g. EfficienSea, ACCSEAS, MONA-LISA, SMART navigation, SESAME, and the STM Validation projects). These attempts to exchange routes will 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 quarter’s situation where the COLREGS will apply.

Route exchange would for instance allow each ship to send several waypoints ahead of the ships present position though AIS to all ships within radio range. Ships can then see other ships intended routes. 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 (Porathe & Brodje, 2015).

4.3 *A Route Network Topology Model*

Autonomous navigation will have to be able to tackle complicated traffic situations (like the situation in Figure 1 illustrates). For this collision avoidance algorithms are necessary. However, solving conflicts using automatic algorithms in a dense traffic environment where many ships are navigation manually with humans on the bridge will be a huge challenge and complete success will be uncertain as long as humans are involved. Ship traffic separation and coordination offers, however, a possibility of reducing uncertainty and potentially simplify the traffic complexity.

Already in 1967, IMO approved the first Traffic Separation Scheme (TSS) in the world in The Dover Strait. TSS is a traffic-management route-system where ships in traffic-lanes (or clearways) all sail in the same direction or must cross a lane in an angle as close to 90 degrees as possible. (IMO, 2019).

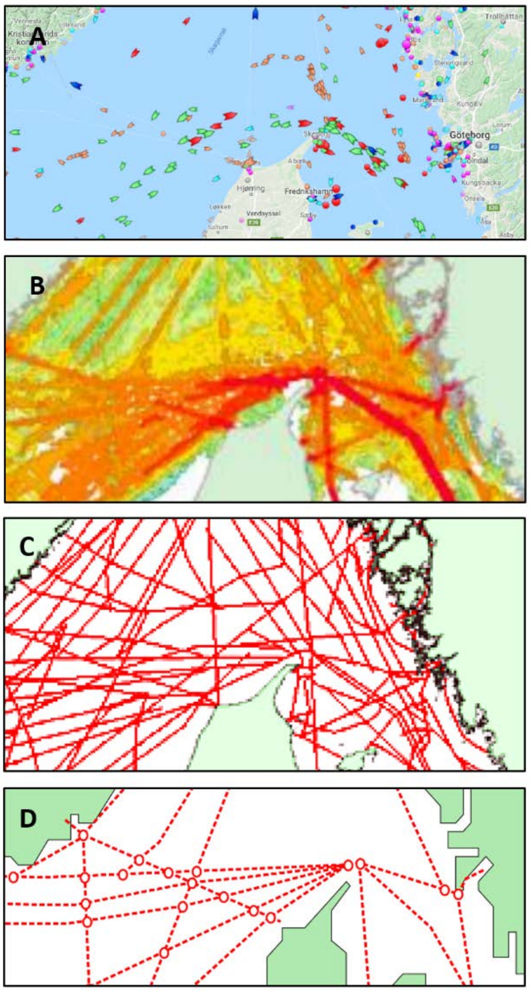

Fig. 4: The top image (A) is the traffic situation in Skagerrak around the northern tip of Denmark on 1 March 2019. Bellow, (B) is a traffic density map based on the number of AIS equipped ships during the whole of 2012 where red depicts the highest numbers. (C) shows a generalization of the AIS tracks deduced from (B) and (D) the final “motorway” route network topology derived from this exercise. (A, screen shot from Marinetraffic.com 2019-03-01, B, C and D from ACCSEAS, 2015b.)

TSS is a good way of simplifying complexity and de-conflicting ship traffic. However, TSS are relatively few although in recent years more and more TSS has been approved by the IMO.

In the EU project ACCSEAS, 2012-2015, where a number of North Sea maritime administration participated as well as academia (including this author), one of the surprising findings was that energy concerns where pushing the development of large-scale wind turbine farms in the relatively shallow southern and central parts of the North Sea (ACCSEAS, 2015a). Potentially we could see that wind farms together with already large areas of oil and gas installations in the future could be a threat to the present-day shipping lanes. Taken into consideration increased world population and thereby increased ship traffic and potential of additional future development of off-shore fish farms, a North Sea Region Route Network Topology Model was suggested where present-day vessel traffic density maps were used to construct a network of traffic separated shipping lanes (ACCSEAS, 2015b).

The process is illustrated in Figure 4. The result was a network of traffic separated shipping lanes of different sizes, from multi-lane "motorways (Figure 4, bottom) to smaller "by-roads" (not shown in the Figure). The hypothesis is that implementing such a network of shipping lanes would greatly facilitate the task of traffic separation in the perspective of autonomous ships.

With a route network and a central mechanism for coordination, autonomous ship separation would be facilitated. However, the manual ships would also need to be coordinated (see "route exchange" in section 4.2 above). For this there needs to be some kind of tool to help the human OOW to keep his position in the flow. A suggestion could be "moving havens."

4.4 *Moving Haves*

When submarines move submerged in groups they cannot see or hear each other. To avoid underwater collisions, they use a coordinated voyage plan in three dimensions. Each submarine is designated to a "moving haven" visualized as a cube, moving in 3D space. The own submarine's motions are tracked by an inertial navigation system and the navigator's task is to keep the sub within its designated haven. Given that all subs in the group do their bit, they can see everyone's position in the chart, and also wind forward in time along the voyage plan to look at future positions (Porathe, pers. com.).

The same system can be used in ship traffic management to visualize coordinated voyage plans of many ships. Fuel efficient, "green" voyages is much about slow seaming and just-in-time arrival. To achieve this a carefully timed voyage plan can be created by a central coordination mechanism based on the requests and performance data from each ship. Due to unavoidable delays or changes in the availability of the arrival port, etc. the coordinating mechanism will keep updating the plan during the entire voyage. While the AIS system will visualize the position of each ship in the electronic chart system, the "moving haven" will visualize the planned and coordinated position where the ship is supposed to be. If all ships stay in their moving haven, close quarter's situations can be avoided. At least in theory. In reality there are e.g. fishing boats and leisure crafts that are not part of the system. But a system of TSSs where the traffic is regulated could be possible. Figure 5 shows a simplified view of a moving haven.

Fig. 5: A simplified visualization of the "moving haven" in an electronic chart. The dotted lines show planned route, and the box show the position where the ship is expected to be according to the plan. The green triangle is the ships AIS symbol based on GNSS input and should be kept in the box. In a 4D electronic chart, a time-slider would allow e.g. a VTS operator with an ability so see all ships' moving havens, to move forward in time and discover future choke points.

5. Conclusions

I have in this discussion pointed at some challenges facing developers of collision avoidance software.

Much of this has to do with the qualitative nature of COLREGS vis-á-vis the quantitative needs of real-life situations.

However, also the interaction between traditional ships in "manual mode" is from time to time problematic. The introduction of autonomous ships which in their navigation follows a machine interpretation of COLREGS might lead to many more problems if not implemented carefully.

It is of great importance that the maneuvers of autonomous ships are predictable to human operators on manual ships. The AI onboard has a potential to become much "smarter" than humans, and to be able to extrapolate further into the future and thereby behave in a way that might surprise people ("automation surprise"). Instead the software should focus on behaving in a humanlike manner.

Such automation transparency might consist of MASS showing its automatic navigation mode (the purple light), the content of its situation awareness (which vessels are observed – and thereby which are not observed) and its intentions. Intentions can be shared e.g. using route exchange technology developed in recent e-Navigation projects like EfficienSea, ACCSEAS and MONALISA.

Only if other mariners can understand the workings of MASS, a peaceful coexistence is possible.

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References

ACCSEAS. (2015a). ACCSEAS Baseline and Priorities Report. http://www.accseas.eu/content/download/2743/25720/ACCSEAS%2520Baseline%2520and%2520Priorities%2520Report%2520v3.0.pdf [Acc. 2019-03-24]

ACCSEAS. (2015b). ACCSEAS North Sea Region Route Topology Model (NSR-RTM). http://www.accseas.eu/publications/accseas-route-topology-model [Acc. 2019-03-24].

Crosbie, J.W. (2006). Lookout Versus Lights: Some Sidelights on the Dark History of Navigation Lights. *Journal of Navigation* 59(1): 1-7.

van Dokkum, K. (2016). *The COLREGS Guide* (6th ed.). Vlissingen, The Netherlands: DokMar Maritime Publisher.

IALA, the International Association for Aids to Navigation and Lighthouse Authorities. 2008. *VTS Manual*. https://www.iala-aism.org/wiki/dictionary/index.php/Ship_Safety_Zone [Acc. 2019-02-10]

IMO, the International Maritime Organization. (1972). *Convention on the International Regulations for Preventing Collisions at Sea, 1972, (COLREGs)*. London: IMO.

IMO. (2018). Regulatory scoping exercise for the use of Mari-time Autonomous Surface Ships (MASS). MSC 100/5/6, 12 October 2018. London: IMO.

IMO. (2019. Ships' Routing. London: IMO. http://www.imo.org/en/OurWork/Safety/Navigation/Pages/ShipsRouteing.aspx [Acc. 2019-02-10]

Kongsberg. (2019). Autonomous ship project, key facts about YARA Birkeland. https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/4B8113B707A50A4FC125811D00407045?OpenDocument [Acc. 2019-03-24]

Lee, G.W.U. & Parker, J. (2007). *Managing Collision Avoidance at Sea*. London: Nautical Institute.

NTSB, National Transportation Safety Board. (2009). Allision of Hong Kong-Registered Containership M/V Cosco Busan with the Delta Tower of the San Francisco–Oakland Bay Bridge San Francisco, California November 7, 2007. Washington DC: Accident Report NTSB/MAR-09/0, PB2009-91640.

Porathe, T. (2006). *3-D Nautical Charts and Safe Navigation*. Vasteras: Malardalen University Press.

Porathe, T.& Brodje, A. (2015). Human Factor Aspects in Sea Traffic Management. In V. Bertram (ed.), *Proceedings of the 14th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '15).* Technische Universität Hamburg- Harburg.

Porathe, T., Hoem, A., Rodseth, O., Fjoltoft, K. & Johnsen, S.O. (2018). At least as safe as manned shipping? Autonomous shipping, safety and "human error". In S. Haugen et al. (eds), *Safety and Reliability – Safe Societies in a Changing World*. London: Taylor & Francis Group.

Statistics Norway. (2016). Various indicators from the operational area of VTS centres. https://www.ssb.no/191461/various-indicators-from-the-operational-area-of-vts-centres [Acc. 2019-02-10]

Rodseth O.J. & Nordahl H. (2017). Definition for autonomous merchant ships. Version 1.0, October 10. 2017. Trondheim: Norwegian Forum for Autonomous Ships. http://nfas.autonomous-ship.org/resources-en.html [Acc. 2019-02-10].