

# Maritime Autonomous Surface Ships (MASS) and the COLREGS: Do We Need Quantified Rules Or Is “the Ordinary Practice of Seamen” Specific Enough?

T. Porathe

Norwegian University of Science and Technology, Trondheim, Norway

**ABSTRACT:** Maritime Autonomous Surface Ships (MASS) is currently on the agenda in several countries and also in the IMO. In Norway a 120 TEU container feeder is being build and will start sailing autonomously in 2022. The challenge is huge. One question is whether or not the present, quantitative, collision regulations needs to be updated to rules where expressions as “early” and “substantial” are quantified? Or if ships can sail autonomously under the present rules? Another question is if MASS should be marked to signal that the ship is in autonomous mode? Or if it is enough that she follows COLREGS? This discussion paper will take a closer look at these questions and advocate *automation transparency*, meaning that the behavior of an autonomous vessel has to make sense and be understandable to human operators on other manned ships and crafts.

## 1 INTRODUCTION

Large autonomous merchant vessels are still on not for real. However, in Norway the building contract is already signed for *YARA Birkeland*, the first Mari-time Autonomous, Surface Ship (MASS), an un-manned 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 quite high. With an autopilot in “track-following” mode, set so that the ship can execute turns along a pre-planned route without acknowledgment from the Officer of the Watch (OOV) - 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 inshore route from Bergen to Kirkenes (Porathe, pers. comm.). But the OOW still has to 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 with the International Regulations for Preventing Collisions at Sea, COLREGS for short (IMO, 1972). With such a system it is speculated that a ship in autonomous mode may navigate automatically.

However, such an “automatic ship” does not need to be unmanned. It may contain a maintenance crew, or even a reduced number of navigators who take manual watches during difficult conditions, or maybe daytime watches in good conditions, saving the automation for the long boring night watches or uneventful oversee passages. With such a partly manned bridge the ship would have a “periodically unattended bridge” according to IMO’s latest definitions, (IMO, 2018).

The watch can also be handed over to a Shore Control Centre (SCC) that can access the ships sensors and communication, ready to wake up the OOW if something unexpected happens (in which case the ship is “remotely monitored”). Or, the SCC could be granted 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, maybe a combination of remote monitoring and control, and autonomy.

It can also be useful to consider the concept “Operational Design Domain” (ODD) used by the self-driving car industry (Rodseth & Nordahl, 2017). In the maritime domain, it would mean that there will be certain shipping lanes and fairways where 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 autonomously, while the ship in other areas must navigate manually with a manned bridge or remote controlled from the shore.

The concept of OOD also has deeper implications into the culture of vessel traffic in specific areas. More on this later.

For the discussion in this paper the focus will be on ships in “autonomous mode”, regardless of whether it is permanent or only periodically. With “in autonomous mode” I mean that a computer program is navigating, taking decisions and executing them, regardless of whether an OOW is standing by on the bridge, or the captain is in his cabin onboard or in a remote centre ashore. The focus here is on how the ship automation can handle interaction with other ships, and particularly how it could follow the rules of the road, the COLREGS.

## 2 THE COLREGS

For several centuries ships came and went, sailing with the same wind and tide and it was not until the steam ships turned up in the beginning of the 19th century that collision regulations became vital (Crosbie, 2006). In 1840 the London Trinity House drew up a set of regulations, one of which required a steam vessel passing another vessel in a narrow channel to leave the other on her own port hand. The other regulation relating to steam ships required steam vessels on different crossing courses, so as to involve risk of collision, to alter course to starboard and pass on the port side of each other. The two Trinity House rules for steam vessels were combined into a single rule and included in the Steam Navigation Act of 1846. During the years a number of iterations and internationalizations, through what is now the International Maritime Organization (IMO), led to the latest revision of the International Regulations for Preventing Collisions at Sea (COLREGS) on an international conference convened in London in 1972.

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 that question is unknown, but it is my firm opinion 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 need to adhere to, is the COLREGS. Having said that, one might consider if extensions or revisions may be needed.

### 2.1 *Qualitative rules*

The collision regulations are, like legal text often is, written in a general manner so as to be applicable in as many situations as possible. The precise interpretation has to be made in the context of the actual situation judged not only on knowledge of the rules, but also on experience and culture, what the rules call “the ordinary practice of seamen,” as is stated already in the second rule.

The qualitative nature of COLREGS will be a problem for the programmer who is to write code for the collision avoidance algorithms of autonomous navigation modules. I will in this section point to some these “soft,” qualitative, clauses where these problems will become apparent.

### 2.2 *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 you have 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.”

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

### 2.3 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 strait forward given that present course and speed can be extrapolated. (This is, however, in reality not always the case as the intentions of the other ship may not be known.) If the bearing to the other ship is constant over time, it can be assumed that there exists a risk of collision. 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 clock minutes what constitutes “early”, neither how large course change or speed change constitutes “substantial”.

Rule 17 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.”

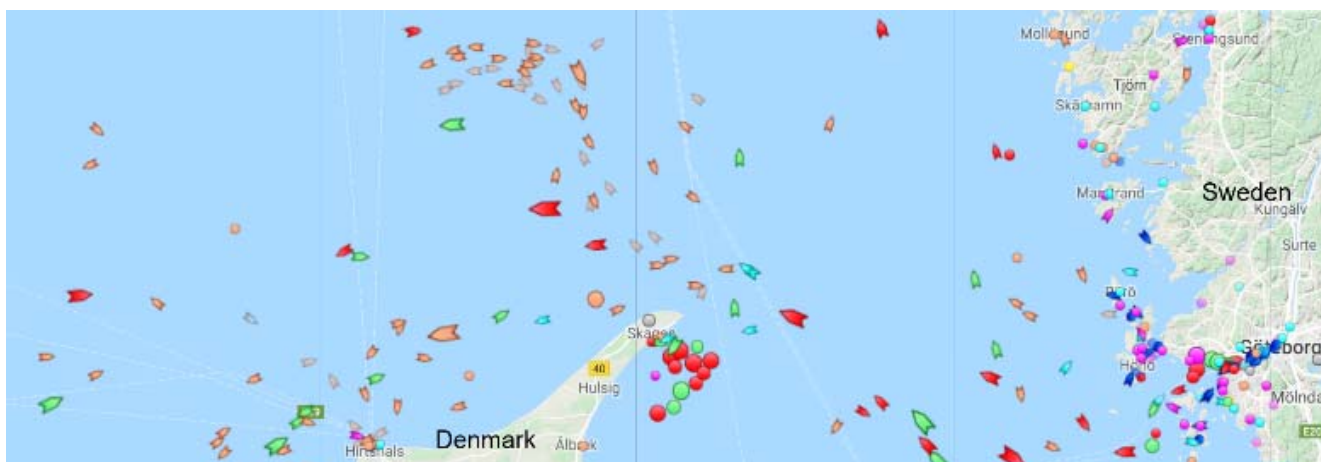


Figure 1. This was the traffic situation at Skagen, the northern tip of Denmark at 15:00 on 5 November 2018. One may reflect on the difficulties of COLREG algorithms needed to do collision avoidance in such an area where giving way to one ship might lead into another conflict situation in an unpredictable,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

For a programmer programming the collision avoidance module of an autonomous navigation software the difficulty is not only in judging which action, but also 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.

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, 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 a programmer trying to catch “early and substantial” as well as “the ordinary practice of seamen” for a specific area (an ODD) could be to study large amounts of AIS (Automatic Identification System) data for the specific area in questions and from that data deduce limits of “early” and “substantial action”. A useful concept could then be ships “safety zones” which is the zone around ones ship that navigators 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 mentions that “As a general guideline, attempt to achieve a CPA (closest point of approach) of 2 (nautical) 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 terms 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 LIDAR. But even if sensor resources on an autonomous ship could be judged as being better than the human eye, 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 the autonomous ship itself 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 all possible situations will have to be very long and he would still not suffice. The unknown unknowns, *black swans*, would keep appearing.

From a computer programmer’s point of view, it might seem 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 will need to have 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, so for the rules of the road to be valid they must be written in a general manner.

Instead it is the algorithms of collision avoidance applications that need 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 for these humans. Autonomous navigation, supported by artificial intelligence on the bridge, has a number of advantages compared to human, manual navigation: improved vigilance, improved sensing 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 several hours ahead of a human navigator but may therefor 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

### 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 working. This in opposition to normal, manned ships, where you always have to be cautious of misunderstandings or violations.

### 4.2 *Identification light*

In my opinion it is therefore important that ships navigation in autonomous mode show some kind of identification signal. It could be an “A” added to their AIS icon in ECDIS or on the radar screen. During dark a light signal could be added (e.g. a purple mast-head all-around light, see Fig. 2).

The assumption above is that if autonomous ships always follow COLREGS their behavior will be a hundred per cent 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).



Figure 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.

### 4.3 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 Do-ver. 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 clearer place 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 *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). But instead *St. Germain* continued her port turn and the two ships collided. *St. Germain* sank, killing a number of 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 important that automation 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 rules of collision avoidance. It would be a benefit if the intentions of ships could be communicated, as argued in Porathe & Brodje (2015). 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 (SOLAS) 1974 applies; namely: a passenger ship engaged on an international voyage, or a non-passenger ship of 500 tons’ gross tonnage or more engaged on an international voyage (IMO, 1980).

SOLAS ships must transmit their position and some other information using AIS. 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. Several passed and ongoing projects aim at collecting voyage 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.

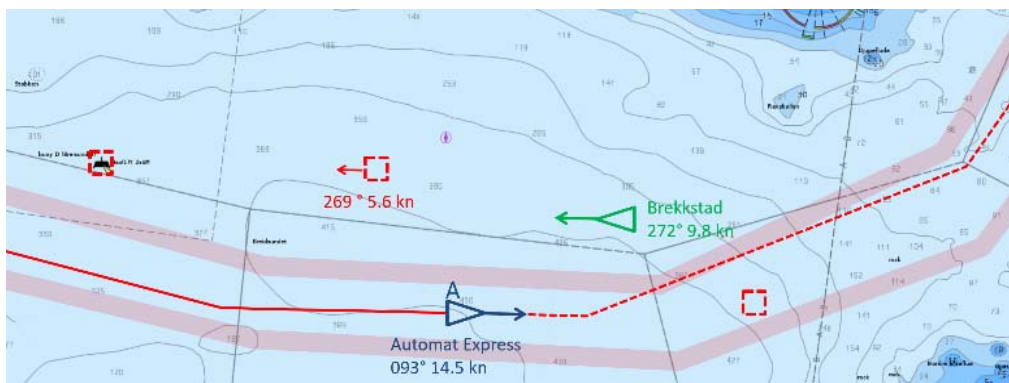


Fig.3: Example of automation transparency: An on-line chart portal showing the situation awareness of the autonomous ship (here *Automat Express*), where she thinks she is, what other ships and objects she has observed, and what intentions she has for the close future. An “A” is added to the AIS symbol for “I am navigating autonomously” and the intended route shown could also be visible in ECDIS and radars of ships in the vicinity.

Route exchange would for instance allow each ship to send a number of waypoints ahead of the ships present position through AIS to all ships within radio range. All ships can then see other ships intended route (as in Fig. 3). 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).

## 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-à-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 navigation mode (the purple mast-head light = in autonomous mode), 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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