Programming "The ordinary practice of seamen" into the AI-navigator: friendly and communicative interaction design between autonomous and manned vessels

T. Porathe
NTNU, Norwegian University of Science and Technology

Abstract - This paper is aimed at programmers presently being recruited to code behaviour of a new type of automatic ships capable of navigating with an unmanned bridge. Today, navigation might be summarised as "the ordinary practice of seamen", as the collision regulations expresses it. The day after tomorrow, when all ships are automatic, sea traffic management, electronically negotiated, will ensure traffic safety and efficiency. But the challenge will be tomorrow, when automatic ships will have to coexist with traditional manned navigation. To be understandable, the mathematical algorithms governing automated ships must mimic human navigation so that a bridge officer can "read" the autonomous ship's actions. This paper will discuss some issues concerning communicative and friendly behaviour in navigation and how mathematical interpretations of the rules of the road and seamanship will be a challenge for this new field of research. How can we design automatic behaviour that will not only be safe, but also natural and understandable for humans on remaining conventional ships, fishing boats and small leisure crafts? Artificial intelligence has the potential to handle very complex scenarios and extrapolate them further into the future than the human brain can. The risk is that this might lead to automatic manoeuvring that are counterintuitive to mariners on conventional ships. To prevent this, automation must be designed in a transparent manner focusing on clarity. And here there might be a conflict with efficiency in the sense of shortest-route and fuel economy.

Keywords
Maritime Autonomous Surface Ships, MASS, interaction design, Human Factors, automation transparency.

Introduction

First, for non-mariners: Starboard side is the right side of a ship when facing forward. Consequently, the port side is to the left.

COLRREG is the rules of the road at sea, the acronym is short for "collision regulations" as expressed in the Convention on the *International Regulations for Preventing Collisions at Sea*. This convention has been adopted by the International Maritime Organization (IMO). It has been amended several times and the present version dated from 1972 (IMO, 1972). The COLREG is a thin booklet with 38 rules and some annexes that govern behaviour on international waters. National waters might have additional regulation but should not go against the COLREG.

COLREG lay the basis for interaction between ships at sea. The aim is safe and efficient sea traffic and constitute friendly and communicative behaviour among ships.

What is friendly and communicative interaction?

Just what is friendly and communicative interaction in ship navigation? A trivial example could be keeping well to the starboard side on a narrow channel leaving room for oncoming ships on your port side. This is of course in compliance with traffic regulations, COLREG, Rule 9. It is friendly because you are considering the spatial needs of oncoming and overtaking traffic. It is communicative because you signal with your position in the channel that you are leaving room for traffic and complying to a common set of rules which will, hopefully, make your further behaviour transparent. Another example could be using COLREG compliant light and sound signals to announce intended actions (e.g., one short blast/light flash: "I am altering my course to starboard" according to Rule 34). It is communicative by the very intention of the rule, and it is friendly because you show you care about interacting to create a safe and efficient traffic environment.

But you can be more or less friendly and more or less communicative while still complying to the COLREGs. Just like in road traffic a vehicle can be manoeuvred in a more or less aggressive manner. And economic efficiency has great influence on this.

What will change with the coming of MASS?

We are arguably at the dawn of a new era in shipping industry. The IMO is facilitating a new type of ship systems which are capable of navigation without human interference. They have called this ship system Maritime Autonomous Surface Ships, MASS for short (IMOb, 2021). MASS will supposedly be able to navigate automatically with the bridge unmanned part of the time or the whole time, presumably remotely monitored from a Remote Operation Centre with ability to remote control the ship, if needed. Unmanned automatic navigation has hitherto only been seen in small survey crafts or in military systems, but the aim of the MASS project is to introduce merchant ships both in inshore, coastal and ocean waters. If this introduction is successful, we might expect to see automatic and conventional manned ships interact in a new way.

Automation, autonomy, and artificial intelligence

Very briefly: *Automation* is the creation and application of technologies to produce and deliver goods and services with minimal human intervention. An *automaton* is a relatively self-operating machine, or control mechanism designed to automatically follow a sequence of operations or respond to predetermined instructions.

Already in the mid second century B.C., Ktesibios of Alexandria invented a water clock capable of regulating the waterflow as to keep a constant flow. By adapting to changes in the environment this self-controlling artifact changed the definition of what a machine cold do.

But if an artifact relies only on the prior knowledge of its designer, we can say it lacks *autonomy*. A rational agent is autonomous only if it can learn to compensate for partial and incorrect prior knowledge (Russel & Norvig, 2016). Hence the incorporation of *learning* is important to be successful.

This incorporation of what we call machine-learning allows an autonomous artifact to automatically learn and develop through experience without being explicitly programmed. This ability is part of what we call Artificial Intelligence (AI).

From this follows that by encountering different experiences two autonomous artifacts might behave differently although required to adhere to the same set of rules. In our case the artefacts are ships, autonomous agents in a complex traffic environment constructed by human experience and behaviour since centuries.

It is very doubtful that the IMO will ever accept two "AI-captains" that respond differently to the same situation depending on different experience through machine-learning (the way human captains do). Therefore, we can assume that the "autonomous" ships addressed in this paper could be better described as "automatic".

Maneuvering is an important means of communication.

Because COLREGS are based on traditional navigation, it is closely tied to human behaviour at sea as it has evolved during thousands of years. The second rule of COLREG explicitly points to the need to take "any precaution which may be required by the ordinary practice of seamen". For programmers coming from an entirely different domain, it will be a challenge to understand this practice.

Basic to all human interaction is communication. Interaction between ships at sea deals to a large extent with the problem of communicating intentions. Sometimes humans might have the same problem of collision avoidance e.g., when walking around in a crowded city environment: shall we meet to the right or the left of the pavement, how avoid bumping into each other crossing a crowded square? Although communication systems involving flag and semaphore systems, sound and light signals and in the last century voice over radio has been developed, manoeuvring remains the most readily used means of communicating intentions.
The example above of keeping to starboard in a narrow channel is obviously trivial, but it reflects the common practise of (most) seafarers as well as being part of the COLREGS.

Traffic separation might not be so difficult to achieve, using Traffic Separation Schemes (TSS), recommended routes and maybe exclusive MASS lanes. When the e-navigation feature of "route exchange" becomes reality and route intentions are routinely transmitted between ships, things might be easier (Porathe et. al, 2015). But until then collision avoidance will continue to be a challenge. So, how do we program automatic, human readable behaviour into a MASS?

A simple example of how COLREG compliant manoeuvrings can be more or less communicative could be an ordinary crossing situation with risk of collision (see Figure 1). In this a case, Rule 15 states that "the vessel which has the other on her starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel."

In Figure 1 you see two ships approaching each other on a collision course. The figure shows two alternative manoeuvrings, left top to bottom and right top to bottom. The staring situation (Frame 1, left and right) is the same for both scenarios.

First, ship A (own ship) has ship B on her starboard side and should give way according to the rule mentioned above. "Avoid crossing ahead of the other vessel" could be achieved in several ways: for example, by slowing down or turning to starboard, both actions result in passing behind the other ship. Turning starboard is the most common action as turning takes effect faster while slowing down will take longer time to take effect and be visible. The COLREGS further says that any action to avoid collision shall be made in "ample time", be "substantial" and be done in "due regard to the observance of good seamanship" (Rule 8).

In Figure 1, frame two, two different give-way manoeuvres to starboard are illustrated. Both are done at the same "good" time, but the size of the course deviation is different (although the sketch is only schematic and compressed to save space).

Most efficient

In the left column ship A makes only a small course change to starboard (Figure 1, frame 2, left). The manoeuvre is based on a calculation of the precise course change needed to give way and go astern of ship B (assuming it is keeping course and speed, as prescribed in Rule 17) with a predefined CPA (Closest Point of Approach) behind vessel B. The precise CPA will depend on the context: on the open sea it might be 1 or 2 nautical miles, but in confined waters it might only be a few cables (1 cable = 0.1 nautical mile).

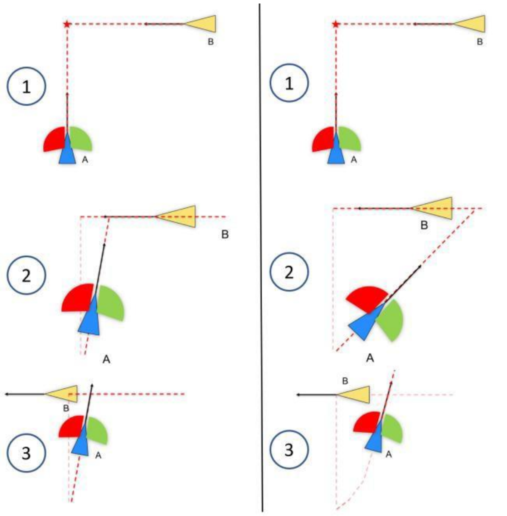

Figure 1. These two scenarios (left and right) show two different strategies for vessel A to give way for vessel B: In the left column a minimal course change is made to achieve the desired CPA, to the right a larger, less efficient but more "communicative" manoeuvre achieves the same CPA. (Illustration by the author).

Most communicative

In the right column, ship A makes a larger course change to starboard and shows her port side (red navigation light at night), and as the meeting proceeds, she turns slowly back to port, all the time with her heading pointing behind ship B, all the time showing her port side and red light, until she is back on her original course. Rule 8 says that an action shall be "substantial", that "any alternation of course and/or speed to avoid collision shall, if the circumstances of the case admit, be large enough to be readily apparent to another vessel observing visually or by radar".

If we compare these two strategies, we can see that the left strategy, route 2 in Figure 2, is the most efficient in terms of shortest sailing route (more fuel efficient), while the right strategy in Figure 1 (route 3 in Figure 2) is longer and thus less efficient in terms of time and energy consumption. (The difference in just one encounter is of course negatable but multiplied by a large number of ships each with a large number of encounters the cumulative effect will be substantial). Both strategies reach the same goal as seen from the perspective of ship A: avoiding collision by a COLREG compliant manoeuvre.

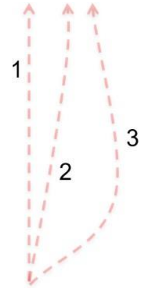

Figure 2. Route 1 lead to the collision so and we must choose between route 2 (more efficient but less communicative) or route 3 (more communicative but less efficient).

On the other hand, let us change perspective, and see the situation from the bridge of ship B, the right column manoeuvring strategy in Figure 1 resulting in route 3 in Figure 2. This manoeuvre is more salient and readable for a human navigator and thus preferable from a communication perspective. A human navigator on ship B will early see the intention of ship A, witch during the whole encounter shows it port side and red navigation light. In restricted visibility (addressed in Rule 19), when ships only see each other by radar, salient manoeuvring is even more important because it take some time for the automatic radar plotting to stabilise and show a targets course on the radar screen.

The dilemma for the programmer is some qualitative variables in the COLREGS:

1) When should the evasive manoeuvre commence? When is the “ample” and “good” time that Rule 8 talks about?
2) How large is a “substantial” a course change, which is among the actions that Rule 8 and 16 mention?
3) What is the CPA needed for a “safe passing distance” the other vessels?

Guidebooks used in maritime training can give some clues:

Ample time

What is the ample time to commence avoidance manoeuvres? When we talk about moving ships, time can also be translated to distance, and we can equally well ask: What the sufficient distance to commence avoidance manoeuvres? Cockcroft and Lameijer (1990) talks about “four stages in a collision situation” (p.129).

Stage 1. At a long range, before risk of collision exists, both vessels are free to take any action.

Stage 2. When the risk of collision first begins to apply, the give way vessel is required to take early and substantial action and the other vessel must keep her course and speed.

Stage 3. When it becomes apparent that the give-way vessel is not taking appropriate action, the stand-on vessel is *required* to give the whistle signal prescribed in Rule 34(d) (at least five short rapid blasts) and is *permitted* to take action to avoid collision by her action alone.

Stage 4. When collision cannot be avoided by the give-way vessel alone, the stand-on vessel is *required* to take such action as will best aid to avoid collision.

The crucial question is of course, the distance at which the various stages begin to apply? The unsatisfactory answer is “it depends”. The distance will be greater for high-speed vessels that for vessels with slower speed. It will be longer for larger, less manoeuvrable vessels than for smaller. It will be greater in a less crowded traffic situation than in a crowded. It will be longer on the open sea than in confined waters. Cockcroft and Lameijer suggests that for a crossing situation in the open sea the outer limit for Stage 2, where a give-way manoeuvre begin, might be in the order of 5 to 8 nautical miles and the outer limits of Stage 3 would be about 2 to 3 miles (p. 130).

van Dokkum (2016) only writes that an action is made in ample time when there is time to spare for the other ship to react to a change of course and speed (pp. 47) there is no set moment when the obligation to give-way sets in.

Lee and Parker (2007) stress the need for early action. They quote a letter to the Nautical Institute where a captain writes “During my time in command I have noticed a deterioration in collision avoidance standards. I feel more threatened as ships seem to approach ever closer before giving way. The only solution I am left with is to assume that other ships will not obey the rules.” (p. 155).

For instance, van Dokkum (2016) notes that during approach to a harbour it is not always possible to comply with the demands of in ample time and at a safe passing distance (p. 48).

A problem might be that a vessel, realizing that she is approaching a situation that might develop into a risk-of-collision situation, still considers herself being in what Cockcroft and Lameijer calls “Stage 1”, at long range, before risk of collision exists, and therefore are free to take any action, while the other ship considers herself already being in “Stage 2” and manoeuvres according to COLREGS. The result might be one of confusion.

Lee and Parker (2007) remarks as a rule of thumb that 7.5 ship lengths can be a minimum distance for when an evasive 90 degree turn with 10-degree rudder must be started (p. 129).

Substantial action

As mentioned above COLREG Rule 8 states that “any alternation of course and/or speed to avoid collision shall [---] be large enough to be readily apparent to another vessel observing visually or by radar; a succession of small alternations of course and/or speed should be avoided,” (IMO, 1972, p. 12) and in Rule 16, “Each vessel which is directed to keep out of the way of another vessel shall [---] take early and substantial action to keep well clear” (Ibid, p. 17).

For the size of a “substantial” course change Cockcroft and Lameijer (1990) suggests that a course change less than 10 degrees might be difficult to detect and hardly can be seen as “apparent”, instead they recommend minimum 30 degrees course change, but preferable in the order of 60 to 90 degrees (p. 65).

van Dokkum (2016) states that a course alternation of at least 60 degrees is clearly visible (p. 83). He also mentions that the Dutch Council of Transport recommends that “showing your other side light when you give way makes it clear to the other vessel that you are giving way and prevents confusion” (p. 49).

Safe passing distance

COLREG Rule 8(d) states that “Action taken to avoid collision with another vessel shall be such as to result in passing at safe distance” (IMO, 1972, p. 12). This "safe passing distance" can be expressed in terms of Closest Point of Approach (CPA). Important to remember here is that there is a definite difference between a CPA in front of another vessel, called Bow Crossing Range (BCR) and passing behind a vessel's stern. When passing behind another ships stern the safe distance can be closer. Passing in front of another ship is not recommended, Rule 15 says "avoid crossing ahead of the other vessel" (Ibid, p. 17).

For the CPA, Lee and Parker (2007) recommend a safe passing distance of 2 nautical miles in open sea and 1 mile in restricted waters (p. 35). However, van Dokkum says that in narrow waters a passing distance of 0.1 nautical miles (behind a vessel) can be necessary (p. 47).

Safe passing distance (CPA) calculation thus needs to take into consideration sea room for manoeuvring (which is much less in confined waters than in open waters).

When demining the time or distance to where COLREG compliant behaviour should commence it might be useful to be aware of the concept of "ship safety zone" defined by IALA (2021) as "A zone around a vessel within which all other vessels should remain clear unless authorised". One may at the same time talk about a ship's "comfort zone" as being the zone around a ship which its watchstander wants clear of other ships. Such a comfort zone would be a psychological concept which will differ from navigator to navigator as well as with the context the ship is in. It should be possible to study the size of such "comfort zones" by processing AIS data – and such an exercise is recommended for the ambitious programmer. The result would probably be very different depending on the context ("it depends", see above), but also the *navigation culture* in a particular area. (What is normal behaviour in the Straits of Malacca?) I would imagine, that by doing such a study on what is "ample time" for a particular area and particular conditions, it could be possible to quantify the time or distance to when to commence some of the qualitative variables COLREG mentions. However, such quantification would only be valid during certain conditions.

The take-away is, that we will not be able to program a set distance for when a give-way ship should start its COLREG compliant manoeuvre, it will be dependent on a lot of contextual variables of which only some are mentioned above. A general advice to the automation programmer new to the maritime domain would be to carefully study maritime accident reports and listen to the discussion carried out by the commission regarding the causes of accidents. And most importantly, get your hands dirty, go onboard, sail and talk to the practitioners.

What will the introduction of MASS change?

Let us bring automatic collision avoidance and unmanned bridge into the simple crossing scenario above. Let us assume assume that the give-way ship (ship A in Figure 1) is navigating automatically. The programmers of the collision avoidance algorithm is faced with the dilemma of a more efficient or a more safe manoeuvre. Of course, COLREGS already talks about evasive manoeuvres bring "substantial" and made in "ample" time. But these entities are contextual and up to the programmer to define and quantify. The question is if salient and readable manoeuvring behaviour will come out on top when put against fuel efficiency and economy? Efficiency in terms of distance sailed and fuel spent (quantitative) might be easier to program than communicative, friendly, and salient behaviour (qualitative). Given that we here are discussing general behaviour for a potentially large number of future autonomous ships, there will be both economical as well as safety implication in the strategy we chose to program into our autonomous navigator.

Multi-ship encounters

In real life situations are mostly more complex than the two-ship encounter illustrated in the beginning of this paper. In reality an evasive manoeuvre for one ship may lead into risk of collision with other ships. Figure 3 illustrates such a complex situation in the English Channel. The black ship A is a ferry coming from Dunkirk destined for Dover. It is approaching the Dover Traffic Separation Scheme (TTS - purple border lines) which divides the English Channel into a south-westbound lane on the English side and a north-eastbound lane on the French side. The lanes have only one-way traffic, but crossing the TTS is allowed – "on a heading as nearly as practicable at right angles to the general direction of traffic flow" (COLREGS, Rule 10c). Sailing up the north-eastbound traffic lane is a number of ships. The blue ships have already passed ahead of the ferry, but the red ship is on collision course and the green ships might pose a problem later, depending on your actions. According to COLREGS all traffic in the north-eastbound lane must yield for the ferry, but the traffic in the south-westbound lane is stand-on in relation to the black ferry. How you deal with this situation if you were programming the collision avoidance algorithm for the black ferry A? Taking on the encounters in the north-eastbound traffic lane

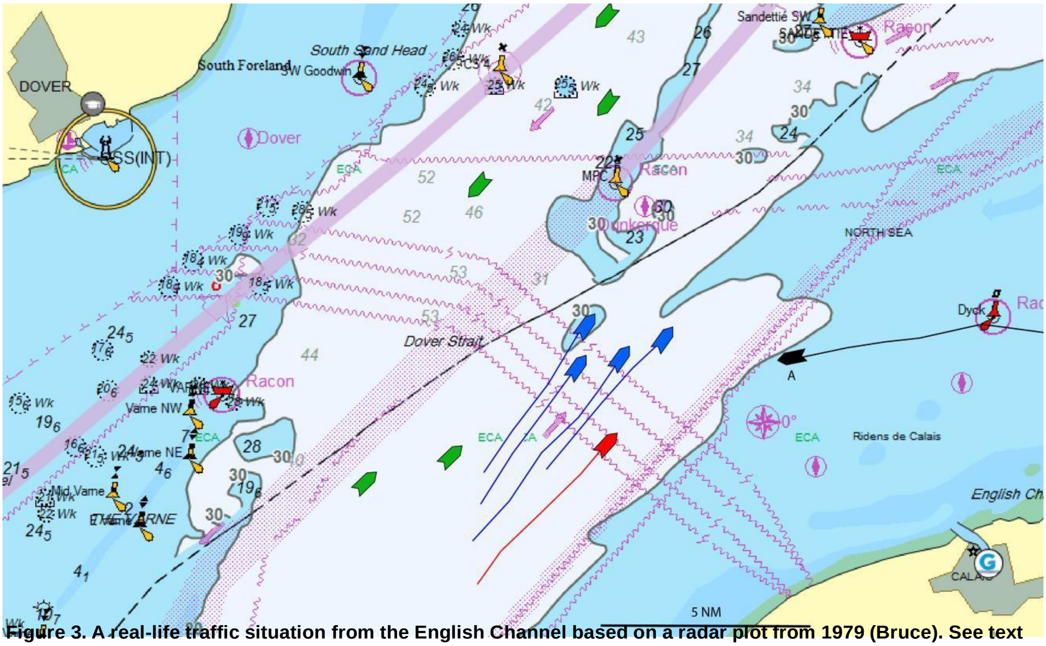

Figure 3. A real-life traffic situation from the English Channel based on a radar plot from 1979 (Bruce). See text for details.

relying on your right of way, could be one strategy, but for the oncoming ships in the south-westbound lane you are the give-way ship.

Take a look at the real-time traffic in the Dover Strait on e.g. MarineTraffic.com. It varies from time to time but for a ferry crossing the Channel it will most often most often be a complex situation. And a general consideration is if you should take encounters "one-by-one", or if you should try and see the bigger picture and set up a more wholistic strategy for the crossing.

The particular situation depicted in Figure 3 are based of an accident that happened in 1979. The black ferry A is the French train ferry Saint-Germain and the red ship is the bulk carrier Artadi. This accident happened in dark and foggy conditions at 4 o'clock in the morning. The black, red and blue ships' positions are all collected from a radar plot submitted by the H.M. Coast Guard at St. Margaret's Bay, Kent, England, and depicts these ships position at 03:52, about 10 minutes before the collision between Saint-Germain and Artadi. All the green ships in the area outside of the radar plot submitted to the accident commission have been added by the author to add to the realism of the scenario. In the following we shall se the choices made by the captains of Saint-Germain and Artadi, as described in the accident report (Bruce, 1979).

The captain on Saint Germain did not want to push his way over the north-eastbound traffic lane. His intention was instead to turn port outside of the of following southwest along outside the border of the TSS, and proceed south-west in the unregulated area outside the TSS until the traffic situation had eased and he could cross the TSS in a right angle according to Rule 10c. The captain on Sain-Germain started to turn port a 03:55.

Onboard the Artadi, the French pilot and the captain had rightly assumed that the radar echo was the ferry for Dover. The assumed she was going to cross diagonally over the TSS and coming from starboard she was the stand-on vessel and should keep her course and speed. So Artadi started a starboard turn at 03:55 precisely at the same time as the Saint-Germain started her turn. They collided some 5 minutes later resulting in the loss of two lives.

Strategies of human and automatic decision-making

The human brain has a limited capacity. A simple example proposed by Miller (1956) suggests that a human only can keep 7 plus/minus 2 "chunks" of information in her short-term memory at any time, and only a limited number of options in a decision-making situation. With the much-extended "brain" capacity, a computer-based automation system could actively hold much more information and compare many more options without confirmation bias and emotional shortcomings well known to human decision-making, and as such plan an efficient route through a complex traffic situation, taking many more factors into consideration, than a human could.

To get an example of human behaviour in such situations, I spoke some years ago with a bridge officer with long experience from car carriers on the Far East-Europe route. When we talked about how to handle the dense traffic situation in the Singapore and Malacca Straits, he said “You cannot really plan ahead, you just need to stick your bow in there and then take each encounter as it comes” (Porathe, personal communication). This is the “opportunistic” way we avoid bumping into one another when walking on a crowded sidewalk.

The captain on the ferry the Saint-Germain, however, tried a more wholistic strategy when he choice to postpone the crossing until the traffic had cleared, unfortunately he did not communicate this intention to the Artade.

Accidents in the maritime domain has been greatly reduced by Traffic Separation Schemes although the story with Saint-Germain and Artade suggests something else. When the Dover Strait TSS was introduced in 1967 the number of accidents diminishes significantly (IMO, n.d.). This suggests that traffic organization have effect on the number of accidents.

In a future scenario with Sea Traffic Management organizing automatic ships on pre-planned routes contiguously communicating delays and other changes, the potential is that we will have safer shipping. For the present, the challenge is to introduce MASS into a conventional human-centred traffic paradigm, with a mismatch between the human and the automatic navigator. In such cases maybe smart and efficient but less understandable, actions suggested by the automation must be sacrificed for less efficient but more understandable manoeuvres? Or should we acknowledge that automatically navigated ships will behave in a somewhat “different” manner and that we instead need to flag them up, so that they become visible for manned ships in the vicinity?

Communicating “autonomous mode”

Given that ships navigating in autonomous mode, using mathematical algorithms might come up with surprising manoeuvring solutions, it could be useful to mark those ships in a way that makes them identifiable. For future MASS it could be evident from their design that they are unmanned and thus automatic, but for a long time one might assume that many ships will be IMO “degree one” ships: “Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.” (IMOa, 2021).

The gradual introduction of increased automation is also supported by real-world projects, such as ASKO and Yara Birkeland in Norway which in the beginning will run in combined human/automatic mode. The next step will be unmanned (remote operated), and final step (if achieved) full automation mode (autonomous).

When such ships are navigating automated and unsupervised, the ship could display some sort of “MASS signal” making its navigation mode salient. For instance, in the ECDIS an added letter “A” (for “autonomous”) could be added to the ship symbol (see Figure 4), and in the physical domain, e.g., a *turquoise* all-round light could be carried in the masthead. In the automotive industry self-driving cars cause some concern when it comes to interaction with other road users, both conventional vehicles and pedestrians. A growing research field are examining whether self-driving vehicles should be equipped with an external Human-Machine Interface (eHMI) to facilitate interactions with human road users. Werner (2018) has studied use of light signals for self-driving cars and is suggesting using a turquoise colour for cars. Cars has to some extent the same light environment as ships where green and red lights are important information carriers. A new light signal must be clearly distinguishable and must not be confused with ship’s navigation lights and lighthouses.

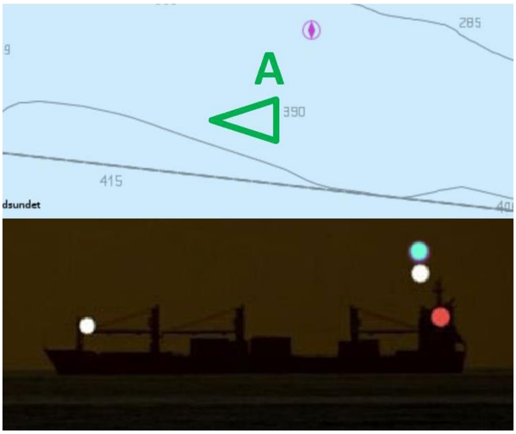

Figure 4. To distinguish ships navigating in an “automates and unsupervised” mode a designated letter (e.g. “A”) could be added to their AIS symbol and a turquoise all-round masthead light could be used.

According to Faas, et al. (2018) the development of standards for eHMI design is in process by the standardization associations Society of Automotive Engineers (SAE International - “Automated Driving

System (ADS) Marker Lamp" - J3134), United Nations Economic Commission for Europe (UNECE - taskforce "Autonomous Vehicle Signalling Requirements" - AVSR). The International Organization for Standardization (ISO, 2018) published the "ISO/TR 23049:2018 Road Vehicles – Ergonomic aspects of external visual communication from automated vehicles to other road users", concluding that an appropriate eHMI design cannot be defined yet. Up to now, there is no agreement on the design guidelines for eHMI lamps.

Some projects are presently looking into the use of turquoise as a designated light colour for self-driving cars (Faas, et al., 2018).

A similar approach should be used for the maritime domain giving it the benefit of a standardised light signal for vessels with "automated behaviour".

VHF communication

If a ships manoeuvring is unclear, a last resort for the bridge officer is to grab the VHF radio handset and ask for her intentions. Traditionally ships communicate using voice over VHF radio. The Automatic Identification System (AIS) revolutionised ship communication in 2002 by making it possible to see the names and call signs of ships in the vicinity directly on the ECDIS screen. Thus, ship could be called by name instead of calling e.g. "ship on my starboard side" which had to be used earlier and which sometimes lead to misunderstandings. Due to a limited the number of VHF channels and an increased density of ships it can in some areas become a quite irritating sound environment on the bridge with many ships calling on two or three radio channels simultaneously. Sometimes you might need to stand in line and wait for an opening to make a call. A voice radio call made to a unmanned MASS will be redirected to a shore Remote Operations Centre (ROC) where a human operator will answer. However, this operator might need some time to get into the loop or might be busy supervising another MASS under his responsibility. To minimize the need for asking for intentions a MASS should be as transparent as technically possible with its intentions.

Potentially, VHF voice communication with an automated vessel could be automized. E.g., when intentions of a vessel are called upon, a RPA (robot) could read out the present intentions of the vessel (e.g. keeping course or altering course to …).

Communicating intentions though AIS

In many e-Navigation projects during the last decade *route exchange* and sharing of intentions has been discussed and prototyped (e.g. EfficienSea, MONALISA, ACCSEAS). The concept has been that a ship sends out a number of wayponts ahead of its present position, from its voyage plan though the AIS system. By right-clicking any such ship in the ECDIS and selecting "Show intentions" the ship's immideate route legs will be shown. Ships routeing can for the navigation planner be simplified by the use of "reference routes" presently beeing rolled out by many autorities (e.g. Norway, Sweden, Australia). In Norway reference routes can be found on routinfo.no, some of them being traffic separated (dual lane). An extended suggesion is to make "moving havens" to show not only the intended route but also the precice location of a ship that is part of a ship traffic coordination system. The details of these features are out of the scope of this paper but a summary and further references can be found in e.g. Porathe, et al., 2015 and Porathe, 2020.

Conclusions

In a future traffic situation where all ships are autonomous, where the traffic is coordinated and where MASS necosiate electronically for situations not covered by the traffic managent, we can assume that the safety will be high. But as long at MASS needs to interact with traditional manned vessels, their behaviour needs to be understood on the bridge of manned ships. The risk is that automatic manoeuvring characteristics will strive for efficiency rather than clarity and safety. Human Factors research and input from active seafarers will be crucial in the development and testing of autonomous navigation.

This paper has suggested a concept of "friendly and communicative" behavior as a leading star for the development of this maneuvering characteristic. Some examples of what "friendly and communicative" might mean has also been given. The concluding point here is that the programmers of future MASS navigation behavior must work in CLOSE cooperation with the maritime community. One would think this should be self-evident, but reality has again and again shown that this is often not praxis.

Acknowledgements

This research concepts presented in this papers are found both within the HUMANE (Human Maritime Autonomy Enable) and SFI AutoShip projects, both funded by the Norwegian Research Council, which is hereby gratefully acknowledged.

References

AutoFerry (2021). Autonomous all-electric passenger ferries for urban water transport. NTNU, Retrieved from https://www.ntnu.edu/autoferry [Acc. 2021-03-28]

Bruce, D.J.F. (1979). Decision of the commissioner of Maritime Affairs, Republic of Liberia in the matter of the collision of the Liberian bulk cargo vessel Artadi (O.N. 3592) and the French RoRo/Train ferry SAINT-GERMAIN in the Dover Strait on 21 February 1979. Office of the commissioner for maritime affairs, Republic of Liberia.

Cockcroft, A.N. & Lameijer, J.N.F. (1990). *A Guide to the Collision Avoidance Rules (Fourth Edition) Incorporates the 1987 and 1989 amendments*. Newnes, Oxford, UK.

Van Dokkum, K. (2016). *Rules of the Road for Marienrs: The COLREGS Guide (6th edition)*. Dokmar Maritime Publishers. Ijmuiden, The Netherlands.

Faas, S.M., & Baumann, M. (2019). Light-Based External Human Machine Interface: Color Evaluation for Self-Driving Vehicle and Pedestrian Interaction. Proceedings of the Human Factors and Ergonomics Society 2019 Annual Meeting. DOI 10.1177/1071181319631049

IALA. (2021). International Dictionary of Marine Aids to Navigation https://www.iala-aism.org/wiki/dictionary/index.php/Ship_Safety_Zone [Acc. 2021-11-29]

IMO, International Maritime Organization. (n.d.) .Historical background on ships' routeing, https://wwwcdn.imo.org/localresources/en/OurWork/Safety/Documents/Ships'%20routeing/Historical%20background%20on%20ships.pdf

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

IMOa, International Maritime Organization. (2021). Outcome of the regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS). MSC.1/Circ.1638, 3 June 2021

IMOb, International Maritime Organization. (2021). Autonomous shipping, https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx

ISO, International Organization for Standardization (2018). Road Vehicles: Ergonomic aspects of external visual communication from automated vehicles to other road users (ISO/TR 23049:2018). Retrieved from https://www.iso.org/standard/74397.html [Acc. 2021-08-01]

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

Miller, G. (1956). The magical number seven plus-minus two: some limits on our capacity for processing information". *Psychological Review*, 63 (2): 81–97.

SAE International, Society of Automotive Engineers (2019). Automated Driving System (ADS) Marker Lamp (J3134). Retrieved from https://www.sae.org/standards/content/j3134_201905/ [Acc. 2021-08-01]

Porathe, T., Brodje, A., Weber, R., Camre, D., & Borup, O. (2015). Supporting Situation Awareness on the bridge: testing route exchange in a practical e-Navigation study. In A. Weintrit, & T. Neumann (Eds.) *Information, Communication and Environment: Marine Navigation and Safety of Sea Transportation*, London: CRC Press, 85-92.

Porathe, T. (2019). Maritime Autonomous Surface Ships (MASS) and the COLREGS: Do We Need Quantified Rules Or Is “the Ordinary Practice of Seamen” Specific Enough? In A. Weintrit (ed.) *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation*, 13(3), 511-517.

Porathe, T. (2020). Ship Traffic Organization with Moving Havens: Ship and Shore Perspective. *Proceedings of the European Navigation Conference ENC 2020*, on-line 23-24 November 2020.

Porathe, T. (2021). Human-Automation Interaction for a Small Autonomous Urban Ferry: a Concept Sketch. Proceedings of the European Safety and Reliability Conference, ESREL 2021 (in press).

Russel, S. & Norvig, P. (2016). *Artificial Intelligence: A Modern Approach*. Pearson, Harlow, U.K.

UNECE, United Nations Economic Commission for Europe, Taskforce on Autonomous Vehicle Signalling Requirements [AVSR] (2019). Draft agenda: 3rd meeting (Report AVSR-03-10). Retrieved from https://wiki.unece.org/download/attachments/75532788/AVSR-03-10-rev1e.docx?api=v2 [Acc. 2021-08-01]

Werner, A. (2018). New Colours for Autonomous Driving: An Evaluation of Chromaticities for the External Lighting Equipment of Autonomous Vehicles. *ColorTurn*, 2018. https://wiki.unece.org/download/attachments/75532788/AVSR-03-02e.pdf?api=v2 [Acc. 2021-07-29]