Deconflicting Maritime Autonomous Surface Ship traffic using Moving Havens

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Maritime Autonomous Surface Ships (MASS), are now on the agenda of the International Maritime Organization (IMO). In several countries research on autonomous navigation is ongoig. If realized, MASS will for the foreseeable future need to cooperate with traditional manned ships on the oceans and the interaction between automatic and manual ships will become a major concern. A primary goal for MASS research is that an autonomous vessel should behave just like any other ship and follow the rules of the road. This paper starts out by looking at a normal, trivial accident and points to e-Navigation as a solution to interactions problems present both in todays manned shipping, which might become even more apparent with future interaction with MASS. A new concept of Moving Havens will be presented to visualise ships intentions both in the geographical and time domain. The concept has been investigated in some earlier e-Navigation projects regarding Ship Traffic Management, but for MASS it might become a means of deconflicting traffic. The concept has been tested technically but needs more thorough research in simulator studies to study human-machine interaction effects.

Keywords: Maritime Autonomous Surface Ships (MASS), Collision avoidance, COLREGS, Moving Haven, information visualization, ECDIS.

1. Introduction

Starting with the EU project MUNIN in 2013 (MUNIN, 2012) an increasing interest in commercial “autonomous” ships (MASS) has risen. It has been portrayed as a possible game-changer for the shipping industry, Hill (2019), claiming increased safety by less human error, e.g. Wise (2018); Edwards (2020), increased sustainability by slow steaming and just in time arrival, e.g. UNCTAD (2018); Saraogi (2019). Big industries like Kongsberg Maritime and Rolls Royce has claimed this as being the future for shipping, Kongsberg (2020); Baron (2019), and some attempts are presently underway claiming to be the first commercial autonomous commercially trading ships, Massterly (2020).

But there are huge challenges for autonomous ships to tackle. One is collision avoidance, Porathe and Rodseth (2019). On the oceans today some 53 000 conventional ships move some 90 per cent of the global trade. Although accidents and incidents happen all the time, modern technology and procedures have made headway. The Allianz Global Corporate & Specialty (AGCS), a global corporate insurance carrier, stated in a press release in June 2019: “Shipping losses lowest this century, down by a record 50% annually and 55% below the 10-year average.” Allianz (2019). So, something must be right in maritime research and development. The Allianz review goes on to state that within autonomous shipping “Progress continues to be made but technology is not a panacea if the root cause of incidents and losses is not addressed.” Of maritime accidents and incidents some 11% (Allianz) to 22 % (EMSA, 2015) is ship collisions.

There are IMO instruments used in deconflicting maritime traffic. The oldest is the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS), now in its 1972 edition. For autonomous ships to become successful teammates on the world’s oceans automated collision avoidance behaviours will be of major importance and increasing research efforts are put into this area, e.g. Johansen (2016); Geng et al. (2018); Brekke et al. (2019); Kufoalor (2019); Ramos et al. (2019); Wang et al. (2019).

As part of the Autonomous Shipping JIP, which began in November 2017, the “first ever autonomous vessel trials held in the North Sea by a Dutch consortium”. The trials resulted in a conclusion that “As yet, the systems behaviour does not yet match a human operator, who considers the overall picture and the development of the sometimes complex traffic pattern when taking action. The artificial intelligence strategy has to be developed further, as well as the capacity of the software to learn. It was concluded that further development of autonomous systems is needed to cope with complex marine traffic situations including foul weather, traffic separation schemes and restricted waters.” de Jong and van Heel (2019).

A conclusion from the research is that it would be beneficial to reduce the complexity of the traffic situation in order to simplify collision avoidance for autonomous ships. Specially to enhance cooperation with conventional manned

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shipping. The scope of this paper is to suggest some Ship Traffic Management features from e-navigation research. As a frame of reference, let's look at a trivial but not uncommon collision incident in the North Sea.

1.1 *The Erin Wood and Daroja collision*

In August 2015 two ships collided on the Scottish coast east of Peterhead. The small bunker barge *Erin Wood* had left North Shields, England in the evening the day before. Her destination was Scrabster, on the Scottish north coast. This small vessel had a crew of only two, the captain and a deck hand. *Erin Wood's* speed was 9.5 knots.

In the afternoon the next day the general cargo vessel *Daroja* sailed from Aberdeen, at about the same time as *Erin Wood* passes the port a few miles out to sea. *Daroja* was destined for Lerwick in the Shetland Islands and as she reached open sea her speed was set to 14.5 knots. The second officer was at the bridge having the con. Figure 1 shows a map of the area with the two ships routes plotted.

Soon after leaving Aberdeen the watch on *Daroja* was taken over by the chief officer. At the time of collision, the watch officers on both ships were seated on their respective bridge chairs. *Daroja's* chef officer on a chair with the back towards starboard side and so low that he could only see the sky looking forward. *Erin Wood's* captain on a chair with his back towards the vessels port side. None of them could see each other's ships slowly coming closer, until *Daroja's* bulbous bow struck *Erin Wood.* The result can be seen in Figure 2.

One may of course ask how such an accident is possible? The accident investigation concluded that "*Daroja* and *Erin Wood* collided because a proper lookout was not being kept on either vessel." MAIB (2016). The accident report also talks about "complacency and poor watchkeeping practices," and also assumptions that the give-way vessel should keep clear. *Daroja* was in this case the give way vessel both considering COLREGS Rule 15 (giving way to vessels on you starboard side) and Rule 13 (keeping out of the way of the vessel being overtaken). IMO (1972).

MAIB's analysis concludes that human error was the cause. But humans are humans, and complacency, distraction and fatigue is part of humans behaviour. This accident could happen again. Instead the interesting question is what can we do to prevent this type of accidents in the future? Better training? More stringent safety routines onboard? Better bridge layout? Probably so. But we still have a situation where we have a single point of failure on both ships. Could shared situation awareness be part of a solution? This is one of the basic ideas of *e-Navigation*.

1.2 *e-Navigation*

In 2006 IMO approved a proposal by Japan, Marshall Islands, Netherlands, Norway, Singapore, United Kingdom and United States to develop an "e-Navigation strategy". The objective of the proposal was to "develop a broad strategic vision for incorporating the use of new technologies in a structured way and ensuring that their use is compliant with various navigational communication technologies and services that are already available, with the aim of developing an overarching accurate, secure and cost-effective system with the potential to provide global coverage for ships of all sizes," IMO (2006).

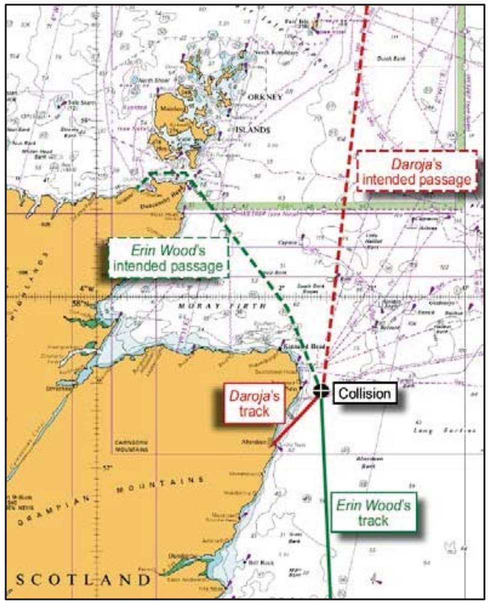

Fig. 1. Intended passages of *Daroja* and *Erin Wood* and collision location, MAIB (2016).

Fig. 2. *Erin Wood* after the collision as seen from the Peterhead lifeboat, including evidence of fuel cargo pollution, MAIB (2016).

The point was to share available digital data to the benefit of safety, efficiency and protection of the environment. As an example: if ships where to share voyage plans among themselves and between ship and shore (such as VTS), single points of failure could be prevented. In many research projects since, possible e-Navigation services have been investigated, one is *route exchange*.

The feasibility to share routes could potentially trigger an alarm if a ship deviated from its planned route and was about to go aground, or if two ships planned to be at the same place at the same time, addressing precisely the accident above. Route exchange in different forms has been researched by e.g. Porathe et al. (2014), Porathe et al. (2015).

But in order to protect against collisions routes needs to be time scheduled so that any position on the route also has an estimated time of arrival (ETA). In essence you can imagine a box that moves along the planned route as the time passes. This is the concept of Moving Havens.

2. Moving Havens

When friendly submarines operate together in groups under water they cannot see or hear each other. To avoid collisions, they use a coordinated voyage plan in three dimensions. Each submarine is designated to one "moving haven" visualized as a cube, moving in a 3D nautical chart. The own submarine's motions are tracked by an advanced inertial navigation system and the navigator's task is to keep the submarine within its own designated box. All boxes are visible to all submarines even if the submarines are not, given that all stay in their boxes, Porathe pers. com.

The same principle can be applied to surface vessels. By visualizing the planned position of ship along its voyage plan with a box, a Moving Haven, the navigation officer onboard can have a quick and intuitive confirmation that he or she is on track and on time. If she strays out of the box, e.g. by inattention or a too strong headwind, there will be a warning and she has to return to her box, or the plan needs to be revised to answer the new situation.

2.1 Moving Havens vs Safety Zones

It is easy to confuse Moving Havens with *comfort zones*, or *safety zones*.

A safety, or comfort zone is an area around a ship that a navigator tends not to let other ships within. IALA (2008) defines it "A zone around a vessel within which all other vessels should remain clear unless authorized.". This zone tends to be larger on the open sea and with low traffic intensity and smaller in narrow waters, in a port or in high traffic density situations. The size of the comfort or safety zone can be studied e.g. using AIS data.

A safety zone always follows the ship. A Moving Haven does not follow the ship, it follows the planed route and the ship must actively manoeuvre to stay in the box.

However, nothing prevents that Moving Havens and Safety Zones are used together to enhance safety. Moving Havens could be a way to deconflict maritime traffic, autonomous or not.

2.2 The width of the Moving Haven

A voyage plan in an Electronic Chart and Display Information System (ECDIS) is made by clicking out way points along the intended route. Some attributes need to be added to this track-line, one of them is *cross-track distance* (XTD). Own vessel's Safety Depth also needs to be set. The safety depth is the needed water depth considering draught, squat and a safety margin. When this is done the route can be automatically checked for under-keel clearance within a corridor limited by the port and starboard XTD (see Figure 3).

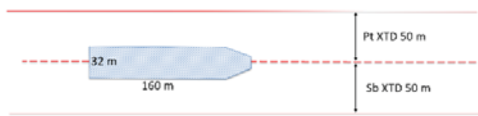

Figure 3: Cross-track distance (XTD), is set to a number of meters on the port and starboard side of the dotted track line. The corridor can then be automatically checked in ECDIS for under-keep clearance. An alarm can also be set to sound if the vessel leaves the corridor.

"When Cross Track Distances are properly set to each leg of a voyage plan then *route checking* assists in checking for potential obstructions, dangers and insufficient depths", London P&I (2018), and warnings are presented if a track line for instance passes over areas with a water depth less than the set Safety Depth. By attributing an XTD on each side of the track in the voyage plan, a corridor of safety checked water can be created for the ship. By tailoring this XTD for each leg, smaller in confined waters or dense traffic and larger in open sea, a dynamic precision in navigation can be acquired. The corridor created by the XTD can for each leg be used as the width of the Moving Haven, giving alarm limits that are more or less rigid. The reason for this might be to relax the attention on a manned bridge or allow a more slack manoeuvring characteristics for the autopilot during heavy weather.

2.3 *The length of the Moving Haven*

The length of the Moving Haven has to do with the needed temporal precision and effective space management in a traffic coordinated system.

The length of a Moving Haven set for a precision of one hour with a ship moving at 15 knots would be 15 nautical miles long. This is not a "box", more like a long "snake". In a time-coordinated ship traffic management system this could result in an inefficient use of water space.

"Just in time arrival" is a logistic concept used to make traffic flows more efficient and decrease greenhouse gas emissions. Traditionally ships would steam along their rout on their standard speed and arrive to their destination early to be able to anchor and issue a Notice of Readiness. Depending on their charter agreement they could then collect Demurrage while waiting for the port to be ready to take them in. However, if the readiness of the port and the arrival of the ship is synchronised the ship might be able to slow steam to its destination and arrive just in time. And because fuel consumption (and accompanying emissions) depends exponentially on the speed, large savings can be made by slowing down.

A port is ready to take in a vessel when all assets are in place: the tide is right, pilots are ready, the required length of birth is free, tugboats and linesmen are in place, etc. There might even be a booked time for a lock passage to reach the berth. In any of these cases a time precision for the arrival will be increasing as the ship approaches port. An assumed precision of 1 minute for a 160 metres long ship moving in 15 knots is illustrated in Figure 4. That Moving Haven is 2.5 cables long (463 meters) and 100 meters wide, assuming an XTD of 50 meters port and starboard. There should be no problem to stay in such a box in nice weather for an autopilot in track-following-mode and a good speed-pilot (autopilot for speed). Heavy wind, waves, currents or engine problems will of course affect a ship's ability to keep a pre-planned voyage and an agreed ETA. In such cases the voyage plan must be re-calculated which will affect the required speed and possibly also the length of the box

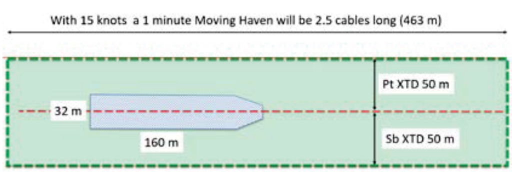

Figure 4: A 1-minute Moving Haven for a 160 meters long vessel at 15 knots will be 463 meters long. The width will be 100 meters with a XTD of 50 meters on either side of the track line. On the ECDIS the colour is green because own ship is in the haven, "on track and on time".

The time-precision (the length of the box) could change dynamically during the voyage. Less at the start and shorter closer to destination. If a ship slips out of its Moving Haven an alarm would be triggered. The ship must then either get back into the box, update the track or recalculate ETAs for the voyage.

2.4 *Alarms*

Alarms could, as mentioned above, be given to the watch officer for the case the ship gets off track or loses its time slot. This could be done first visually with colours, as suggested in Figure 8. If there is no response they could promulgate first within the ship, and finally, in a Ship Traffic Management regime, be sent to a coordinating mechanism, e.g. a VTS, if there is one is in place.

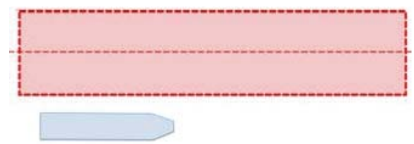

Figure 8: If a ship slips out of its Moving Haven a warning in ECDIS could be a first alert for the watch officer.

In case such a coordinating mechanism is in place and routes are shared the scenario for the example accident with *Daroja* and *Erin Wood*, referred to above, could look like Figure 9 and alarms could be triggered both on the ships and on VTS and the Coast Guard ashore.

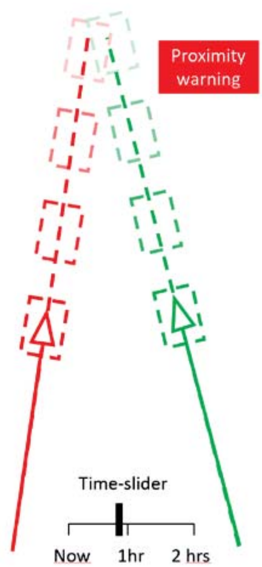

Figure 9: A central coordination system would react if two ships were to approach each other. A warning could be issued both onboard the vessels and ashore. A time-slider in ECDIS

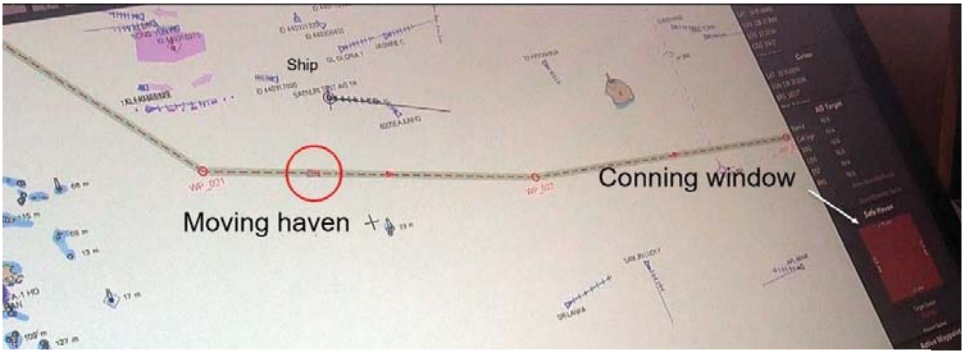

Figure 10: A screen photo from an ECDIS-like prototype display system using a Moving Haven in the sea outside, Wando in South Korea during a test in 2014. The own ship is outside and north of the Moving Haven, Porathe et al. (2014). Photo by the author.

and VTS-systems could function as an investigative tool. Illustration by the author.

In the MONALISA project technical tests with the Moving Haven in the ECDIS-like prototype display were tested onboard two Korean training vessels. Figure 10 shows a screen dump from these tests. For safety reasons the ship was not allowed to navigate using the Moving Haven why the ship on this chart is outside and above the "box" in the red circle. The "Conning window," bottom right, is coloured red to warn for this fact. Porathe et al. (2014).

3. Moving Havens, the ship perspective

A captain would expect the bridge officers to keep the planned schedule and ETA at destination. So, in reality there is a mental ghost ship traveling along the track line during each watch. The Moving Haven only makes this metal construct visible.

Used in this way, onboard a single vessel, the concept is not very controversial and can be used as a visual aid for the watch officer to keep the voyage plan.

However, the real benefit comes when the scheduled plan is shared with other ships in the vicinity, so that ships can see each other's intentions. Not only their intended tracks but also all ships future positions - much like trial manoeuvre in an ARPA – but then the future positions are based on an extrapolated course and speed not the actual intended track. In that way upcoming close quarter situations can be flagged up in advance.

Is it feasible? A concept called *route exchange* has been extensively researched in the EfficienSea, MONALISA, ACCSEAS and the STM Validation projects, e.g. Porathe et al. (2014) and Porathe et al. (2015). This research also includes an *intended route* feature. The route format needed to do this already exists, the so called RTZ-format for route exchange, approved by the International Electrotechnical Commission, IEC (2015) – presently developed by the IHO as S-421. The only thing still missing is a 3-dimentional ECDIS, where the third dimension is time. Such an ECDIS should have a *time-slider* (see Figure 9) where you could reel time forward and follow the intended tracks of your own and neighbouring ships to investigate possible close quarter situations in the near future. But one must be conscious of that sending out intentions also means that other ships can see, and expects you to follow your intentions, the same way that using the turn signal on your car comes with benefits but also a risk if you do not follow your signalled intention.

The alarm connected to the Moving Haven could prevent the type of accidents when a watch officer has fallen asleep and the ship continue straight ahead, out of its box and strands (which happened twice I Sweden in 2018, SHK (2019) and ARX Maritime (2019).

When it comes to both the size of the Moving haven there is a safety-efficiency trade-off: wider and longer boxes would mean increased safety but would also utilize the water less efficiently. In very congested areas like the port of Rotterdam or in Singapore Strait, this needs to be considered. In a full Ship Traffic Management environment where boxes are coordinated against each other so that no two boxes are at the same place at the same time, efficient use of the waterway will be a major concern. On could imagine a pre-planned conveyor-belt slot regime where slots in different directions are coordinated and where ships must wait to "jump into" a free slot. This is still a very controversial idea. One might also imagine that only very large ships are part of such a regime, while lesser tonnage continue business as usual.

In a potential future environment when conventional maned ships must coexist with MASS the Moving Haven concept together with a time coordinated chart system offers a watch officer a possibility to see the automatic vessels intentions, and for the AI on the autonomous ship a chase of "understanding" human intentions.

4. Conclusions

In the accident related at the beginning of this paper two ships collided in calm weather and good visibility. This happened because none of the watch officers kept a lookout although both ship was clearly visible through the windows, on their radar screens and o their ECDIS screens. Nor was anyone watching from shore. Not Peterhead VTS or Aberdeen Coastguard nearby, nor the Royal Navy, although the slowly developing close quarters situation should have been alarming to anyone following the scenario.

The real benefit with route exchange of scheduled routes would be that automatic computing of future positions of the Moving Havens could reveal loss of separation which could be automatically flagged up onboard, and if no action is taken, also flagged up ashore in the VTS or Coastguard. This could prevent the type of single points of failure that the *Daroja* and *Erin Wood* accident was an example of, or the two standings in Sweden briefly mentioned before.

For MASS visualising not only the intended route, but also intended future positions will be crucial.

e-Navigation is about delivering new means of safer and more efficient navigation. Route exchange offers the technical possibilities, but human operators both onboard and ashore will need simple and intuitive means visualising ships geographical and temporal intentions. This will be important as we approach a possible new reality where manned and unmanned ships must coexist o the seven seas.

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