Ship Traffic Organization with Moving Havens: Ship and Shore Perspective

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Abstract: *e-Navigation is a concept launched by the IMO in 2006. The point is to share digital data to the benefit of safety, efficiency and the environment. Every ship must make a voyage plan before leaving berth. Sharing such voyage plans between ships and between ships and shore is called route exchange and such a feature would allow alarms to be triggered both onboard and ashore if a ship deviate from its planned route, or if two ships plan to be at the same place at the same time. To visualise correspondence or lack of correspondence between the planed position and the real position the concept of Moving Havens is suggested. It is a visualisation tool designed to intuitively show if a ship falls out of its safety checked position. In case of route exchange and Ship Traffic Management it will facilitate for land-based operators or automation to distinguish dangerous situations. The concept is presented in this paper.*
The same method is suggested as a tool to increased awareness and safety in the context of a future mixed environment of Maritime Autonomous Surface Ships (MASS) and traditional manned ships.

1. Introduction

In all human activities, accidents happen. To prevent this *safety barriers* are introduced. In the maritime domain, ships approaching an unknown coast run the risk of grounding or collision due to lack of local knowledge of reefs and fairways. Many centuries ago, *pilots* were hired onboard. They could be fishermen with knowledge of the dangers and traffic in their local waters, and as a ship proceeded along the coast they were exchanged for a new pilots with knowledge of their waters. An example can be found in an old Scandinavian itinerary from the 13th century describing *The fairway of King Valdemar* along the Swedish east coast, naming local homesteads where pilots could be exchanged [1]. But safety barrier may have “holes” as Reason [2] illustrated in his “Swiss cheese model.” For instance, a pilot may be unaware of a particular danger or may even fall asleep. After an accidents, new safety barriers may be created in order to prevent a repetition. With the advent of radio communication in the 1910’s and radar surveillance after WWII, the ability to support ship navigation from shore became a real possibility. The first Vessel Traffic Service (VTS) was for instance established to oversee traffic in and out of the Liverpool docks in 1949. But this new this safety barrier has holes as well. Let us look at a Norwegian accident from 2018:

1.1 The *HNoMS Helge Ingstad* accident [3]

In the early morning hours of November 8, 2018, the Norwegian frigate *HNoMS Helge Ingstad* was transiting the inshore area of Hjeltefjorden in western Norway, north of Bergen. The frigate was under way from a NATO exercise in middle Norway to Scotland for a navy visit. During this transit the vessel was training bridge officers in inshore navigation and on the bridge was

not only the officer of the watch (OOW), assistant OOW, lookouts and a helmsman, but also a trainee OOW and a trainee assistant OOW.
At 02:38 the frigate entered Fedje VTS zone covering the Bergen area. Being a navy ship in home waters the *Helge Ingstad* was exempt from using AIS. But on entering the VTS area the frigate phoned the VTS on cell phone, reporting on its arrival and planed route through the VTS area. The frigate was visible on the VTS radar but without AIS label with name and call sign.

Figure 1. The traffic situation in the Hjeltefjord at approximately 0345. The frigate had one southbound vessel just ahead, and three northbound and one southbound vessels south of the Sture terminal. Sola TS and the tugs Ajax and Tenax had now left the quay and started a port turn to set a northbound course towards Fedjeosen. HNoMS Helge Ingstad was directly to the east of Nordøytåna, 5.65 nm to the north of Sola TS. Illustration: AIBN [3].

As *Helge Ingstad* was proceeding south in the fjord, the 250 m long tanker *Sola TS* was preparing to leave birth at the Sture terminal further south fully loaded with crude oil. At 03:13 the pilot onboard called Fedje VTS and reported that the tanker had started to take in the mooring lines and was preparing to leave the birth. At 03:40, *HNoMS Helge Ingstad* was approximately 7 nm north of the Sture Terminal in the Hjeltefjord, moving at a speed of between 17 and 18 knots. Five minutes later the pilot of Sola TS reported that the tanker was leaving the terminal. She was turning 180 degrees to proceeded to ramp up speed northbound in the Hjeltefjorden. She had six forward-pointing yellow deck lights on the forward side of the superstructure was turned on as well as three forward-pointing white lights in the foremast. This because the crew was securing the deck for rough weather on the North Sea. Fig. 1 shows the situation at 3:45 from the illustration of the accident report. *Sola TS* blue - turning) is turning around to take her northbound course. Southbound vessels *HNoMS Helge Ingstad* (red -18 knots) and pleasure yacht Dr. No (gray - 9 knots) are just visible to the north. South of *Sola TS* the three northbound vessels (yellow) *Silver Frida* (10 knots), *Vestbris* (9 knots) and the *Seigrunn* (speed not indicated in the accident report) are visible.
At the same time, 03:45, the watch handover started on the bridge of *HNoMS Helge Ingstad*. In the interviews conducted by the accident investigation board, the bridge crew indicated that they had not identified Sola TS as a vessel under way, but thought the brightly lit object visible in front of the terminal area was some kind of static object or part of the terminal.
At 03:58, the pilot on *Sola TS* called Fedje VTS asking: 'Do you know what vessel is approaching towards us? She is slightly to port.' The operator at Fedje VTS replied: 'There is

… have not received any information about it. It has not been reported to me, I only have an echo on the screen here.' Fig. 2 shows the situation at 3:51 from the radar of *Sola TS*.

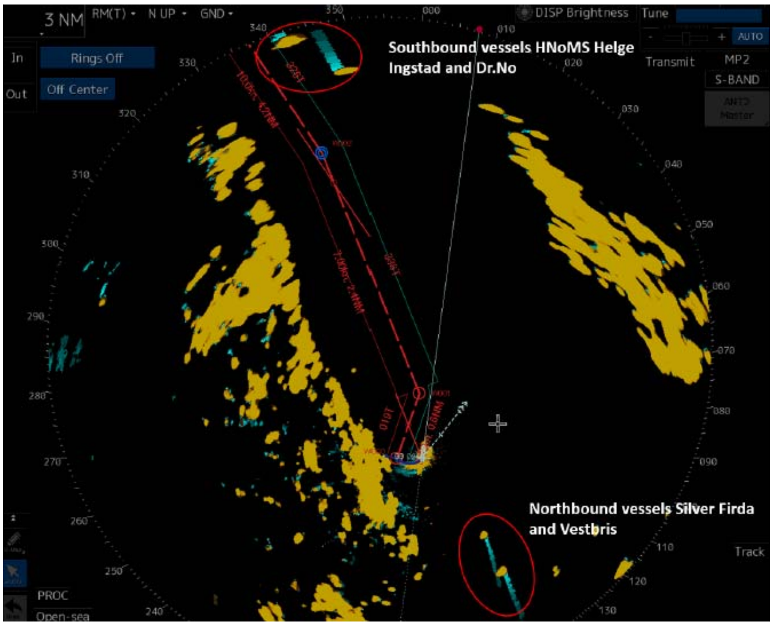

Figure 2. The traffic situation as displayed on the S-band radar on Sola TS at 03:51. Source: Tsakos Columbia Shipmanagement S.A. [3].

After receiving the call from *Sola TS*, the VTS operator plotted the radar echo without AIS and the vectors was indicating that *Sola TS* and the other vessel were on course to collide. "Some time" after receiving the first call from the pilot on *Sola TS*, the VTS operator remembered that *HNoMS Helge Ingstad* had previously (at 02:38) notified of entering the VTS area. The VTS operator immediately called the pilot on *Sola TS*: "It is possibly *Helge Ingstad*; he entered from the north a while ago. It could be that he is the one approaching." The OOW on *Helge Ingstad* became aware of the VHF call and went over to the VHF radio to reply.

At 04:00, the pilot on *Sola TS* called *Helge Ingstad* and requested: "Turn starboard if you are the one approaching."

The OOW on *Helge Ingstad* replied: "I … a few degrees to starboard as soon as we have passed eh …, passed eh … the platform on our starboard side". He later indicated in the interviews with the accident investigation board that the thought he was talking to one of the three northbound vessels on his port bow. Seen slightly to the east and southeast of *Sola TS* in Fig. 3.

At 04:01 *Sola TS* and *Helge Ingstad* collided resulting in the subsequent sinking and total loss of the frigate. No lives were spilled and no serious damage to the environment was reported. The OOW of *Helge Ingstad* only in the final seconds realized that the "object" was in fact a vessel under way. He claimed he never saw the navigation light, blinded by the strong deck lights of *Sola TS*.

The Accident Investigation Board Norway concluded that: "Organisation, leadership and teamwork on the bridge of *HNoMS Helge Ingstad* were not expedient during the period leading up to the collision"(p. 145). That "The shipping company of *Sola TS* had not established compensatory safety measures with regards to the reduction of the visibility of the navigation lights due to deck lighting" (p. 146). And that "Lack of monitoring by the VTS meant that the operator's situational awareness and overview of the VTS area were inadequate. [---] The functionality of the monitoring system with regards to automatic plotting, warning and alarm functions, was not sufficiently adapted to the execution of the vessel traffic service. The NCA had not established human, technical and organisational barriers to ensure adequate traffic monitoring" (p. 147).

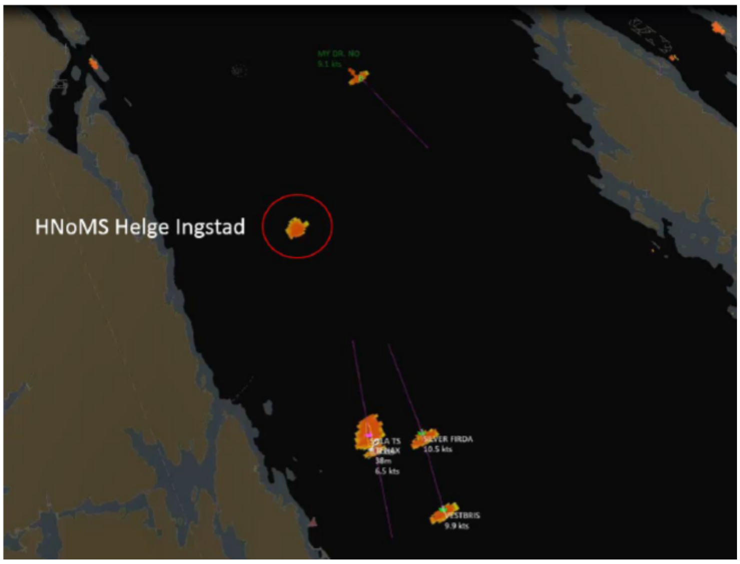

Figure 3. Screenshot of the radar replay from Fedje VTS, showing the traffic situation near the Sture Terminal at 03:59. Source: NCA

2. The Vessel Traffic Service

Vessel Traffic Service (VTS) is an international service that is managed in Norway by the Norwegian Coastal Administration to improve safety at sea and protect the environment. The maritime traffic control centres prevent incidents and accidents by monitoring and regulating ship traffic in defined areas along the Norwegian coast [4]. The VTS offers three types of services based on national regulations and international recommendations: INS, NAS and TOS. The official NCA page describes their services in accordance with the VTS manual of the International Accosiation of aids to navigation and Lighthouse Authorities (IALA) [5] as: *Information Service (INS)*. This service shall provide important information at the right time to support the nautical decision-making processes on board. A vessel can request information, and the VTS centre can provide unsolicited information and ask the vessel questions if something is unclear. Information can include:

- Information on the traffic situation, such as position, identity of the vessel, destination.
- Meteorological and hydrographic information.
- Relevant limitations or activities in the fairways.
- Guidelines for mandatory reporting.
- VHF channels that are used in the VTS area.

Navigation Assistance Service (NAS). Navigation assistance is established either on request from a vessel or when the VTS operator observes irregular navigation and the VTS operator deems it necessary to intervene. The vessel and VTS centre will agree on when the navigation assistance service starts and stops. This service entails assistance that is linked closely to the vessel in question. Examples of navigation assistance situations:

- Difficult meteorological conditions.
- Faulty or defective equipment on board.
- Vessels that deviate from a sailing plan.

- Assistance en route to an anchorage site or pilot embarkation buoy/area.
- Risk of running aground or collision.
- Vessel that is uncertain of its position, or not able to determine its position.

The VTS Centre can provide:

- Bearing and distance to nearby hazards or landmarks.
- Recommend a course to the next waypoint.
- Position in relation to the fairway axis, navigation functions, and/or waypoints.
- Provide support and information on the current traffic situation to the crew on the bridge.

Traffic Organisation (TOS). The purpose of this service is to prevent hazardous situations from developing and to ensure safe and efficient navigation through the VTS area. The VTS centre provides information, advice and instructions to vessels. Vessels report before sailing into the VTS area, or when leaving an anchorage site or dock in order to avoid traffic congestion that can create critical situations.

The Maritime Traffic Regulations regulate, for example, meeting and passing bans, and granting a vessel clearance to sail into a VTS area. Clearance can be granted without conditions, but special conditions can also be stipulated through:

- Use of special fairways.
- Sailing in a specific order in relation to other traffic.
- Clearance can be withheld when there is a valid reason for doing so.

Looking at the description above it looks as the regulatory framework for providing an efficient ship traffic management are available. However, looking at the traffic situation in Hjeltefjorden at the night of the accident gives a picture of ships coming and going much on their own accord along with a longstanding tradition of ships managing their own navigation under the collision regulations. One may argue that a tighter traffic management regime where ships for instance receive traffic slots to which they must obey, might be motivated in dense traffic areas like the Singapore Strait or the Port of Rotterdam but would be overkill in the sparsely trafficked Hjeltefjorden. However, as we started out saying, accidents happen anywhere and what we are investigating here is a new safety barrier, another slice of the swiss cheese, if there are technical means to efficiently do so.

Although we could easily blame the human operators at the sharp end for this quite unnecessary accident I will in this paper point to the possibilities of using technology made available to the maritime community thanks to the *e-Navigation* development.

3. e-Navigation

The basic technologies of electronic navigation (apart from radio and radar) came with the Global Positioning System (GPS) and electronic chart plotters in the 1980's and 90's. At about the same time in the maritime domain the Swedish pilot Benny Pettersson started experimenting with transmitting GPS positions through the Ship Position Exchange System (SPEX), later to be named Automatic Identification System (AIS) [6]. AIS became mandatory by the IMO in 2002.

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 where to share voyage plans between ships and shore (such as VTS). The objective was to prevent "single points of failure" such as a ship straying off its course, whether deliberate or because a watch officer was making an error or falling asleep. In many research projects since, possible e-Navigation features have been investigated. The feasibility to share routes has been called "route exchange" and could potentially allow alarms to be triggered, first onboard and later ashore, if a ship deviated from its planned route. Route exchange in different forms has been researched by e.g. [7, 8]. However, there are also cases where alarm triggered by off-track, or shallow water cannot prevent accidents.

The IMO guidelines for voyage planning [9] also mentions the need to determine the estimated time of arrival (ETA) both at the destination and "at critical points for tide heights and flow". Until recently standard format for route exchange has not included speed settings and ETA at waypoints. However, in the MONALISA projects [10, 11] the author took part in work which resulted in the so called RTZ-format for route exchange, approved by the International Electrotechnical Commission in 2015 [12]. This format allows precisely that, and would allow time coordinated voyage plans to be compared for the existence of "loss of separation", i.e. if two ships planned to be in the same place at the same time.

In reality, a prediction made maybe days ahead will be inexact as speed might change due to weather, engine performance, sea state and many other parameters. But if the onboard electronic chart system (ECDIS) keeps comparing present and planned positions, safety checks and shares a constantly updated voyage plan with the central coordination mechanism the prediction will become better and better as the time to the predicted moment decreases. In the case of *Helge Ingstad* and *Sola TS* such a system could have alerted the bridge crew on both ships about the predicted close quarter's situation and might have recommended a minor speed change on one or both ships. Furthermore, information about the upcoming situation would have been available in the central coordination centre long before the VTS operator made the manual plotting. Yet another pair of eyes would be alerted and could intervene. However, to simplify for the navigator onboard and the operator in a VTS a visualisation tool is needed. This tool is called *Moving Havens*.

4. Moving havens

When submarines operate together in groups they cannot see or hear each other under water. To avoid collisions, they use coordinated voyage plans in three dimensions. Each submarine is designated to a "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. The other submarines' positions are visible through their havens, given that they all stay in their boxes [13].

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 is on track and on time. If he or she strays out of the box, there is a warning. Fig. 4 shows a simple illustration of the Moving Haven concept using the *Helge Ingstad* - *Sola TS* scenario: Based on the voyage plans of the ships in the VTS area (which have been sent to the VTS using *route exchange,* or based on routes sent from the VTS to the individual ships), the VTS operator will acquire a 4D representation of the situation for the Hjeltefjord. The 4th dimension is time, here represented by the time slider in the bottom left corner. This slider allows the operator to scroll forward in time and he can evaluate oncoming situations as the boxes move according to course and speed set in the voyage plans. The ships will have a similar 4D view on their ECDIS screens and are in normal circumstances expected to stay in their own box. The operator will see the AIS or radar target in respective box as a verification that each ship are within respective box ("on time and on track"). If anyone slides out if their box there will be an alarm. This can be a ridged regime for OOWs (TOS), or less ridged (NAS). The system will constantly look ahead to spot loss of separation between ships (red circle in Fig. 4) even if the operator/navigators in not using the system to scroll ahead in time.

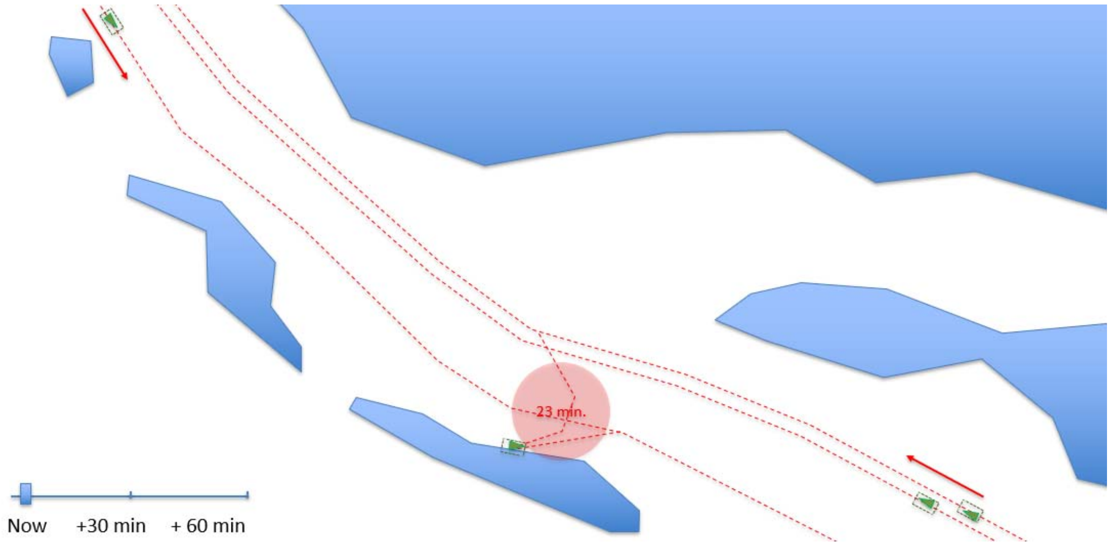

Figure 4. Schematic drawing of the Moving Haven concept using the Helge Ingstad – Sola TS collision as a scenario. Detailed explanation in the text. Image by the author.

For the transparency of route intentions of future Maritime Autonomous Surface Ships (MASS) I think it will be of great importance.

4.1 The width of the Moving Haven – Cross Track Distance
Cross-track distance (XTD) is an attribute of the track line created between waypoints in the ECDIS. 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 and larger in open sea, a dynamic precision in navigation can be acquired. In some cases, the XTD can be different on the port and starboard side, e.g. when the track passes close to a buoy. The corridor created by the port and starboard XTD can for each leg be used as the width of the Moving Haven. See Fig. 5.

4.2 The length of the Moving Haven – temporal precision
The length of the Moving Haven has to do with the needed temporal precision and effective space management in a traffic coordinated system.
If you set the precision to 1 hr with a ship that is moving at 15 knots, the Moving haven would be 15 nautical miles long. This is not a "box", more like a long "snake". In a time-coordinated ship traffic management system where the Moving Haven is used as a "safe haven" which would be exclusive for only one ship, this would mean that the ship would block this whole area. This would be inefficient in congested waters.
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*. 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 pier side 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 estimated time of arrival (ETA) could be less than 5 minutes. An assumed precision of 1 minute for a 160 metres long ship moving in 15 knots is illustrated in Fig. 5. 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 and currents would of course require different dimensions.

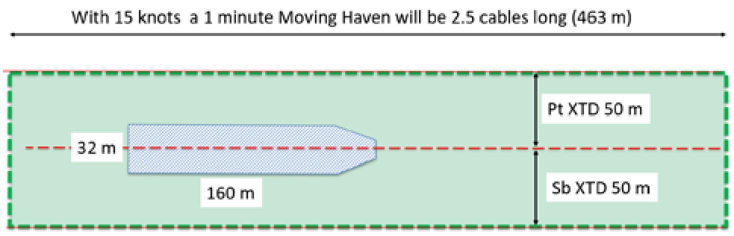

Figure 5. A 1-minute Moving Haven for a 160 meters long vessel at 15 knots will be 463 meters long. The width will be 100 meters with a XTD of 50 meters on either side of the track line. On the ECDIS the colour is green because own ship is in the haven, "on track and on time".

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

4.3 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 Fig. 6 and 7. If there is no response they could promulgate with alarms, first within the ship, and finally, in a STM regime, sent to a coordinating mechanism, e.g. a VTS, if one is in place for the waters.

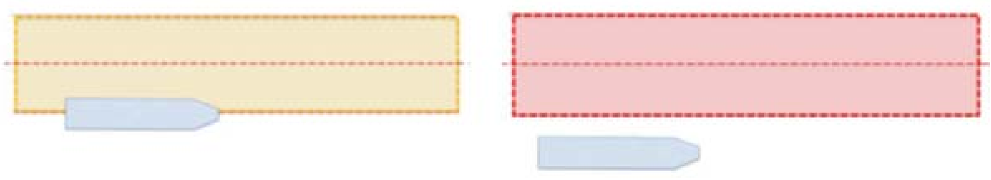

Figure 6. If a ship starts to slip out of its Moving Haven a colour warning could first alert the watch officer.

In case such a coordinating mechanism is in place and routes are shared the scenario for the example accident with *Helge Ingstad* and *Sola TS*, referred to above, could look like Fig. 7.

Figure 7. A central coordination system receiving voyage plans from all ships reacting to is two ships were to approach a point where they would be at the same place at the same time.

In the MONALISA project technical tests with the Moving Haven in the ECDIS-like "e-Navigation Prototype Display" were made onboard a Korean training vessel in the southern part of the Korean Republic. Fig. 8 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. On the "conning display", bottom right, the Haven is coloured red to warn for this fact [7].

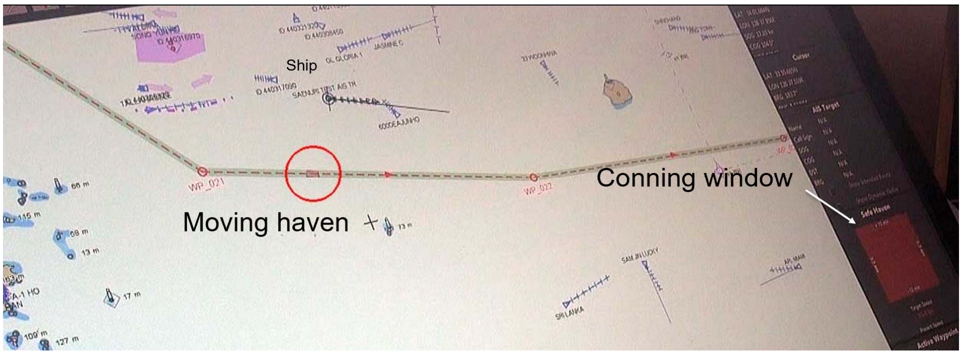

Figure 8. A screen photo from an ECDIS-like prototype display system using a Moving Haven in the sea outside, Wando in South Korea during a test in 2014. The own ship is outside ad north of the Moving Haven [7]. Photo by the author.

5. Conclusion

e-Navigation is about to deliver new infrastructure for sharing route information. This makes it possible to allow ship traffic management systems to survey and intervene in some type of accidents where bridge officers onboard have lost situation awareness (single point of failure). Following a voyage plan for a set destination and ETA means turning up at specified waypoints at specified times, i.e. following a scheduled "virtual position" along a track on the ECDIS. This "virtual position" today often resides in the mind of the watch officer which makes it difficult to share with the outside world. Visualising this "virtual position" with a Moving Haven would make a deviation from the plan obvious for the outside world which then has a bigger chase of intervening.
While the AIS system will visualize the position of the real ship in the ECDIS, the Moving Haven will visualize the planned (and possibly) coordinated position where the ship is supposed to be. If all ships stay in their Moving Havens, close quarter's situations and groundings can be avoided. At least in theory. In reality there are also fishing boats and leisure crafts that are not part of the system. But if at least larger SOLAS vessels are included, safety can be increased.

Acknowledgements

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