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Human Factors in e-Navigation: a study of Dynamic NoGo Area Visualization in Electronic Nautical Charts*

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Abstract

Conspicuous grey shading or blue colours are traditionally used in printed nautical charts to display shallow water. The problem is that what is "deep" water for one size of ships might not be so for another size. To understand the extent of navigable water the bridge crew has to make a number of relatively complicated mental calculations. This paper suggests an automatic way of displaying NoGo areas that will give the bridge officer an at a glance knowledge of his ship's manoeuvrable space, present, and along the future route. A prototype has been developed and was tested in the EU project ACCSEAS with professional mariners. The system was rated as good and acceptable from a professional point of view although there is still improvements to be made.

Keywords: Electronic Nautical Charts, ECDIS, ACCSEAS, NoGo Areas, e-Navigation

I. Introduction

Inbound for Immingham on the English east coast, a ship on her starboard side passes the lighthouse at Spurn Head. In front of her is the seemingly open and inviting waters of the Humber River estuary. However, the view is deceptive because under the muddy surface threatens sandbanks to ground a vessel that is not careful in her navigation. See Figure 1.

I.I. The Nautical Chart.

Nautical charts go back a long time, but not nearly as long as shipping itself. While we in the West have engravings of Phoenician ships a thousand years BC, the first known nautical chart, the *Carta Pisana*, from the Italian city of Pisa, is dated to 1275 AD (Taylor, 1956). However, it was not until the 18th century that the nautical chart started to replace written sailing directions on board ships. Before, the mariner had to follow written sailing directions or take onboard local pilots. With the nautical chart, the mariner suddenly possessed a growing database of geographic knowledge of maybe hundreds of pilots. Nautical charts serves many purposes from being an analogue computer allowing the mariner to construct his present position by *lines of position* and calculate his compass course by measuring the angle from the meridian, to the more downright need to "remove the water surface" to understand what is under. Mistakes can have severe consequences, what the mariner needs to know is "do I have enough water under my keel to go there? Where are my NoGo areas?"
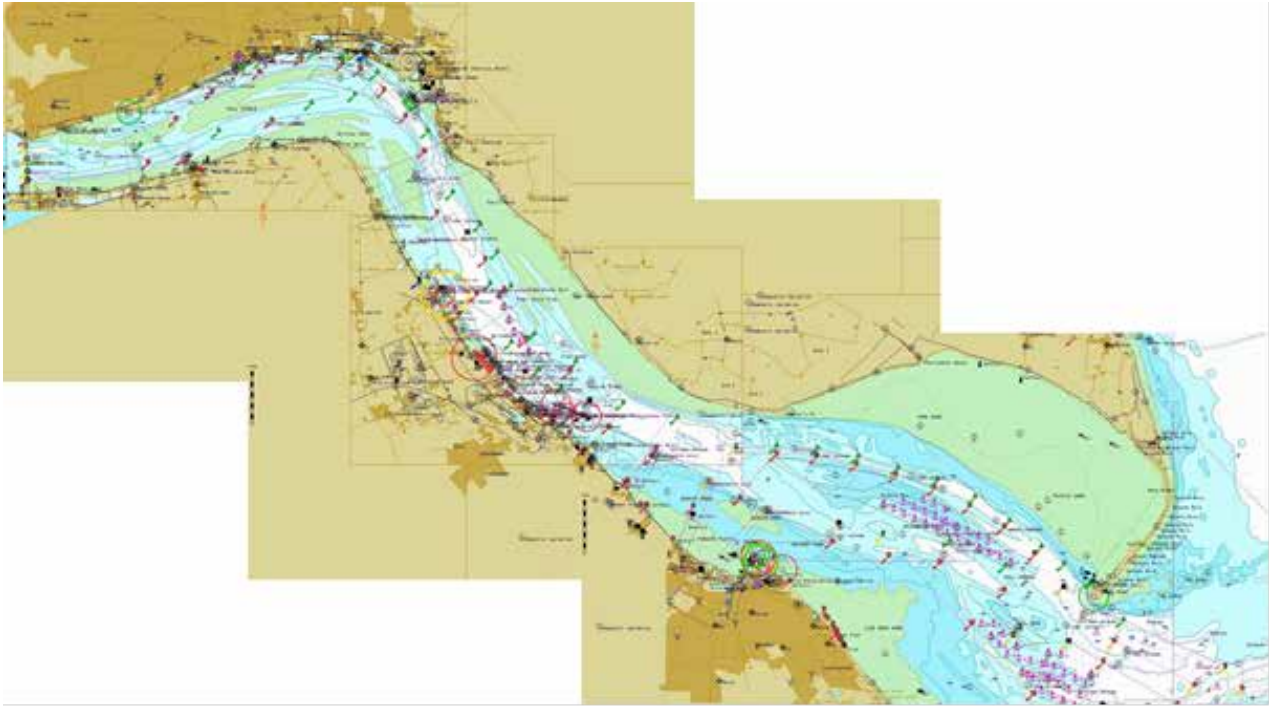
Figure 1. The Humber River and Estuary on the English east coast. Bottom right, at the entrance, is Spurn Head light and up river, the ports of Grimsby, Immingham and Hull (top left). The green areas are beaches drying out on low tide, the blue and white areas are permanently water and with depth contours marking 2, 5, 10, etc. meters depth (on low water)
Source: Mosaic of screen shots from an electronic nautical chart (Transas).

However, because ships have different draughts, the NoGo areas of one vessel might not be the NoGo areas of another. That is the problem of nautical charts: they are too general; to be able to tailor them for a particular ship the mariner needs to make quite some mental arithmetic. For instance, the chart gives a depth of 10 meters. Your ship has a draught of 8.5 meters, and you want a safety margin, an Under Keel Clearance (UKC) of 2 meters. In total, you want 10.5 meters of water, which you do not have. But luckily the tide is rising and is now 2.5 meters. However, there is a high pressure and strong westerly winds lowering the sea level 1.3 meters. On top of that, you have a squat of 0.5 meters and waves with a significant wave height of 0.9 meters. Can you pass the area? Of course these type of calculations are normally done in peace and quite well in advance, but if something happens and the ship needs to make an evasive maneuver or have engine problems and starts drifting, these complex calculations needs to be made on the fly with risk of errors.

In modern electronic charts, a dynamic feature called "safety contours" has been added. This feature makes a selected depth contour (a line connecting similar depths) conspicuous and the areas inside that contour highlighted in one or two blue colors. Compare the images in Figure 2 where the safety contour in the same area is set to 2, 5 and 10 meters (left to right).

Fig. 2. The water area outside Immingham oil terminal in an electronic chart. The safety contour is set to 2 (left), 5 (middle), and 10 meters (right). The contours needs to be available in the chart database, so, for instance, a safety contour of 8.5 meters cannot be set: it will instead be the next deeper contour, 10 meters.
Source: Example screen shots from an electronic nautical chart (SeaPilot).

The problem with safety contours is that they need to be set manually and several groundings have occurred partly due to that this feature has not been used to make shallow waters more conspicuous (FBMCI, 2009; MAIB, 2014). The draught today is read from a gauge painted on the bow and sternpost of the ship before leaving port. The general tidal level can be found in tables on-line. They are derived from historical records taking into account geographical features of the coastline, but the wind effect and atmospheric pressure has to be taken into account. At some places, the total tide can be read from gauge buoys in real time. Squat and heel are displacements of the ship's hull that depend on speed, and wind and must be approximated onboard based on tables made up for each individual ship. Heave depends on the sea state, which in turn depends on old swells, wind and bottom topography. The problem is for the officer on the bridge to deal with this complex information. Often rough approximations are done on-the-fly, with risk of error.

I.II. Dynamic NoGo areas

In 2002 Porathe & Sivetun proposed an automatic feature in electronic nautical charts which would highlight areas too shallow for sailing given the current water level and sea state, and the ships draught and squat (see Figure 3).

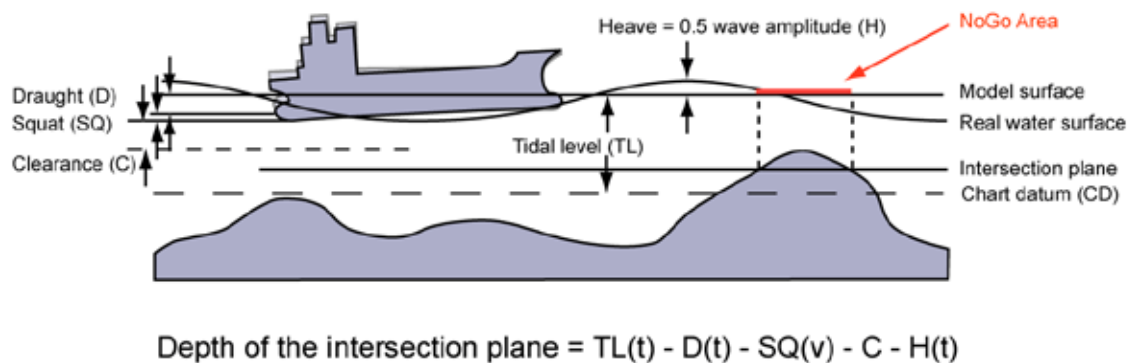$$\text{Depth of the intersection plane} = TL(t) - D(t) - SQ(v) - C - H(t)$$

Figure 3. A simplified calculation of under keel clearance and generation of Dynamic NoGo areas, in reality the parameters also includes parameters of heel, list, water density, and date of bottom survey and siltation allowance (Porathe, 2005; AMSA, 2007)..
Source: Porathe, 2005.

However, this is not enough: the tidal level can change quite drastically on an hourly level, why the mariner needs to monitor not only the present situation, but also plan ahead. Given the economic pressure in the shipping industry, the cost of fuel and the need to keep time slots in locks and ports, the mariner on the bridge is left with a substantial workload managing the voyage.

II.   Method

II.I. Prototype development

A visualization prototype of the NoGo areas was developed for a 3D chart (Porathe, 2006). This prototype was however not tested in formal usability tests. A first working prototype of the NoGo areas in an ordinary electronic chart was developed by the Danish Maritime Safety Administration (now known as Danish Maritime Authority) and Chalmers University of Technology in the EU-project EfficenSea (2012, pp. 16-20). This prototype utilized a high resolution bathymetric database over the Danish side of the Sound between Sweden and Denmark provided by the Danish Hydrographic Office, but the results of the NoGo area calculation was displayed in a relatively course 100 by 100 meter grid. Technical tests were successful but no user tests were carried out this time either.

However, in a sequential EU project, ACCSEAS (2015) the development work was continued in a prototype of the Humber River, the area presented in the introduction to this paper. The area was picked out as a test bed area for several e-Navigation services developed in the ACCSEAS project. The Humber Estuary was an excellent place to test the NoGo areas. The tidewater at Hull ranges from 6.9 meters at spring tide to 3.5 meters at neap. Due to the heavy siltation, navigation in the river is challenged by shifting sandbanks something that makes the Humber port authorities carry out contiguous surveying. While the official chart cells in the Electronic Nautical Chart (ENC) are only updated with long delays, the results of these surveys are published on a bi-weekly basis in the form of survey maps downloadable in pdf format from the Humber Estuary Services (2015). For an example, see Figure 4.
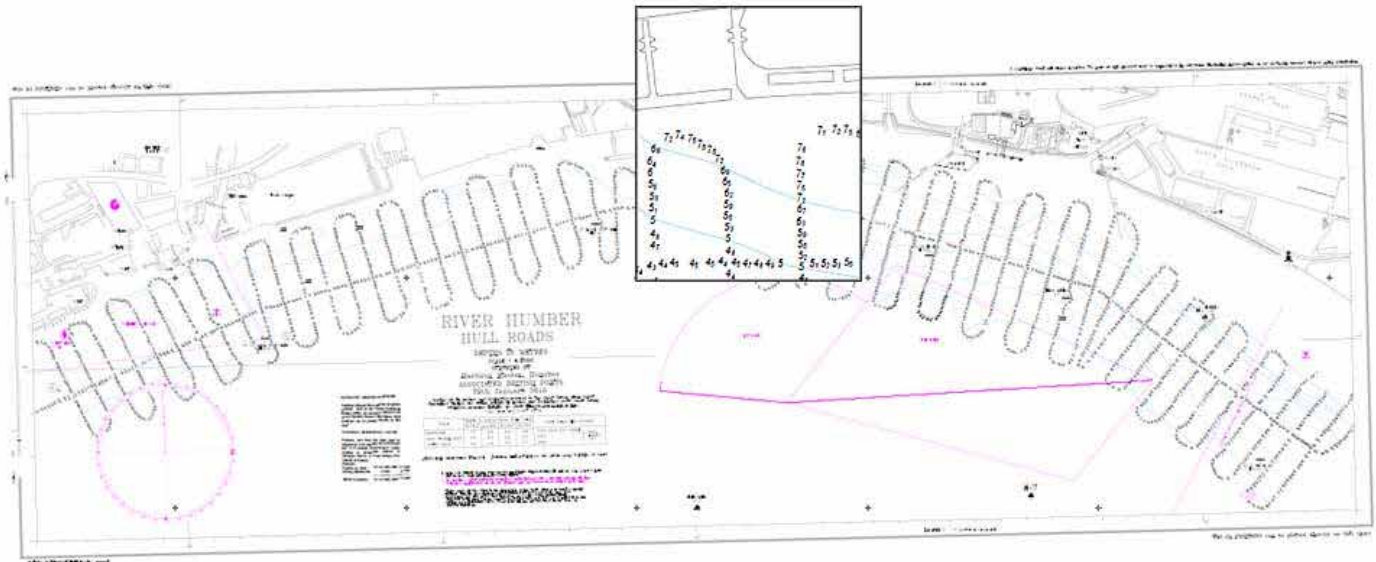
Figure 4. A downloadable survey map from the Humber Estuary Services presenting the results of a survey run along the piers of Hull from 29th of January 2015. In the clos-up the soundings (in meters) is visible.
Source: Humber Estuary Services, 2015

These survey maps represent wery accurate and up-to-date information about the present bathymetrical condition in the river, but from a usability point of view their value are questionable: few ships will have large format printers onboard so they need to be viewed on a monitor using a pdf reader, a tool that do not have any provisions for measuring bearings and distances and that cannot present own or other ships positions from satellite navigation systems. Instead information needs to be carried "in the head" from one screen to the screen of the electronic chart system. In the ACCSEAS project the United Kingdom Hydrographic Office agreed to develop a river database based on the up-do-date Humber Estuary Services' surveys that could be used as basis for the NoGo area service prototyped.

II.II. The tested prototype service

A laboratory ENC test platform, the E-navigation Prototype Display (EPD), was developed in the EfficienSea project. This platform allowed us to prototype the dynamic NoGo area feature in an environment that was very similar to a real ECDIS system used in modern navigation. The system communicated with GPS and AIS and could be used in a simulator environment.

A vessel requesting a NoGo area needs to define 4 points in a bounding-box defining the area for which the NoGo area were to be calculated (the reason for this limitation was to limit the computational demands on the server-side), and a time-slot. The server would then return NoGo area polygons for the worst case (most shallow situation) during that time slot. The user could also ask the system to slice up the time slot in a number of intervals of a certain length. A time slider would then allow the user to flip through the time-sliced NoGo areas.

In the reference implementation, an XML schema was used. However for the future infrastructure developed within the international e-Navigation concept are envisioned to be used.

Input to the calculations was:

1. Manual by Mariner:
   · Vessel draught
   · Wanted Under Keel Clearance; taking into account vessels draught, squat, heave, etc.
2. Automatic:
   · Detailed bathymetry (from database; 1-centimeter depth intervals in a 50x50 meters grid)
   · Tidal information: possible in 10 minute time slices and 1-centimeter intervals for the closest Standard Port (TotalTide).
   · Weather information adjusting astronomic tidal level (not tested during ACCSEAS project).

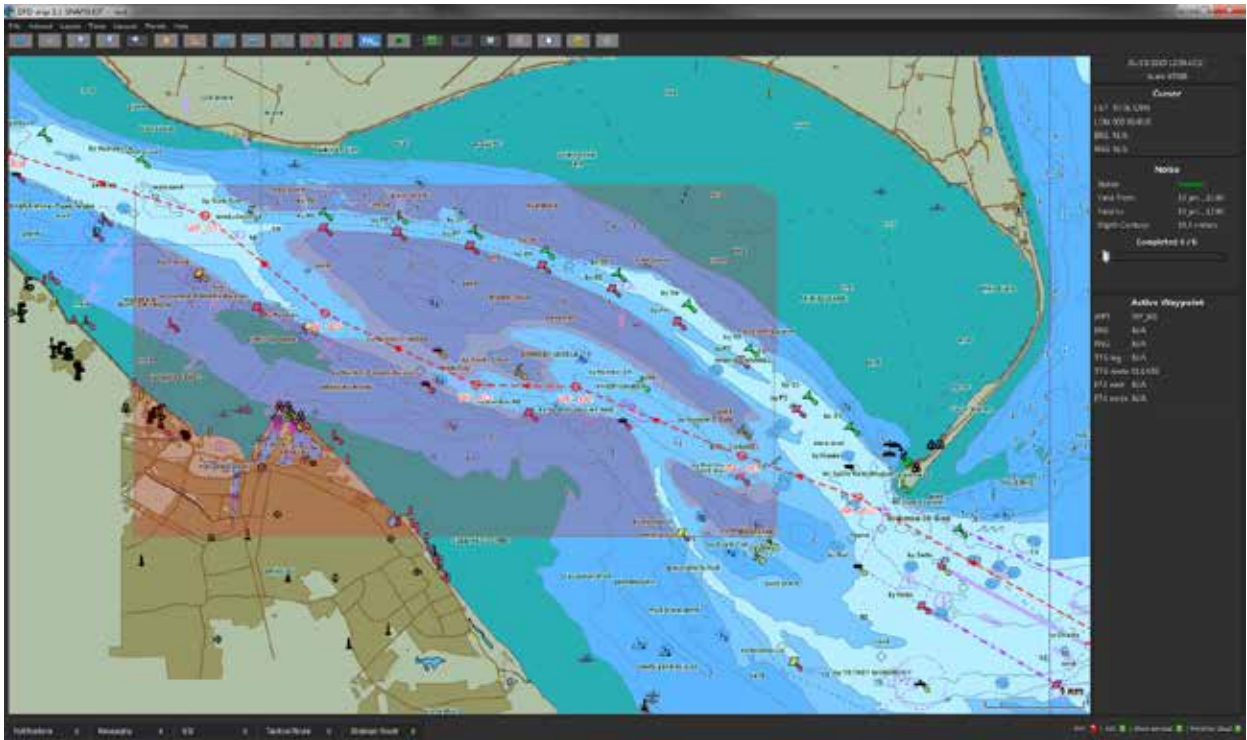In Figures 5 and 6 an example of NoGo areas for the Humber River in the EPD can be seen.

Figure 5. Screen dump from the prototype application. Own ship's planned track is shown as the red dashed line. NoGo polygons for the area within the rectangle drawn on the screen are displayed in a transparent red colored layered on top of the nautical chart. In this case it is the first time slice (of 6) acquisitioned and shows worst case scenario for the time from 11.00 to 12.00 o'clock. The NoGo polygons show that the southern channel is closed for vessel with a draught, plus UKC of 10.5 meters due to low water.
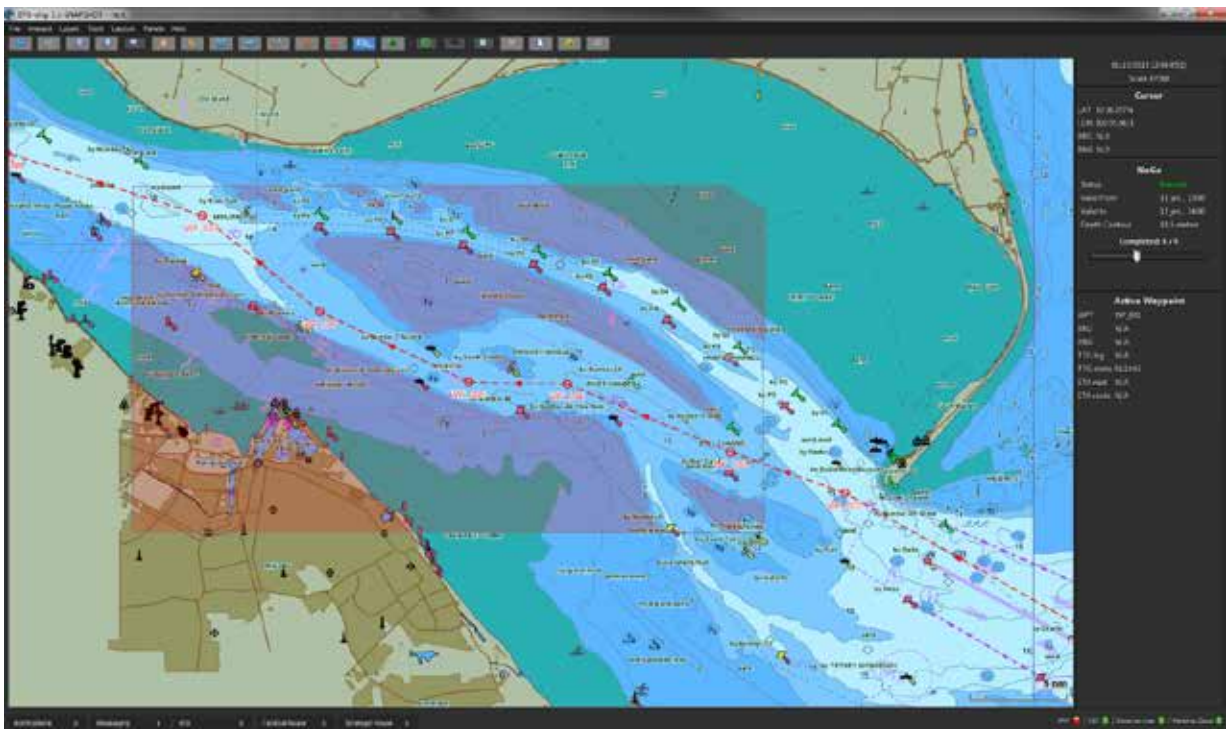Source: Mads Bentzen Billesø, Danish Maritime Authority.

Figure 6. In this screen dump the time handle in the top section of the panel to the right has been moved showing NoGo polygons for the time period 13.00 to 14.00. As the tide is now raising the channel has opened for our vessel.
Source: Mads Bentzen Billesø, Danish Maritime Authority.

II.III. Human-Machine Interface Procedure

Due to restrictions in the data processing capacity of the test implementation, only a limited area could be processed during each request. The procedure for requesting NoGo polygons was as follows:

1. The user right-clicked anywhere in the chart and chose "Request NoGo Area" from a context menu.
2. The Request NoGo dialogue box opened where you set your own ship's draught (automatically copied from the vessels AIS message) and specified an Under Keel Clearance (UKC). If you wanted NoGo areas for different time intervals, you needed to specify that. For example if you chose a time interval of 6 hours and request 6 slices you will get 6 NoGo area overlays, one for each 1 hour period. The system will then calculate NoGo areas for the least favorable depth in each time interval.
3. Finally, the user clicked "Select area" and drew a rectangle for the area in question with the cursor on the screen.
4. There is a delay while the query is sent to the database and the requested number of slices are sent back. The time delay could be substantial depending on the size of the area and the number of slices requested as well as bandwidth for the communication link. During the test, an area of a square nautical mile or so with just one slice would be computed in about 30 seconds.
5. As only one NoGo area slice was visible at a time there was a time slider in the NoGo Area section of the right side bar. This time slider could be pulled back and forward showing the different NoGo areas and the time interval each one was valid for (see Figures 5 and 6).
6. The NoGo polygons could be toggled off and on.

II.IV. User test

The NoGo area service was tested during a four day session in the simulator center at the Department of Shipping and Marine Technology at Chalmers University of Technology in Sweden. A number of different scenarios with ship movements in the Humber estuary were executed. The NoGo area service was tested along with other e-Navigation services. Qualitative data was collected during the simulations with special focus on usability, professional acceptance and unintended consequences of change. Simulation sessions and debriefings were video recorded. The participants were encouraged to think aloud. After each session a video recorded debriefing was held where pros and cons of the features tested were discussed.

II.V. Participants

11 professional British, Swedish and Danish bridge officers, harbor masters, pilots and Vessel Traffic Service (VTS) operators with experience from ship traffic in the Humber area was used for the test. All the participants were male from age 32 to 58, with a mean age of 47 years. They all had a professional experience ranging from 12 to 30 years, mean 22 years.

Each bridge was manned with two bridge officers, which would be realistic considering that the situation was approach to port and constrained waters with heavy traffic.

The Spurn Head simulated VTS was manned with two VTS operators from the actual VTS center.

III.   Results

III.I. Conceptual level

There was an agreement that the dynamic NoGo area service was beneficial, especially for tidal areas as electronic charts today does not take in tidal information. Even if the pilot would know the area at the particular tidal situation, it will supply at-a-glance reassurance for the rest of the bridge team. One of the pilots said that "many times I have had captains look over my shoulder pointing at the ECDIS saying, 'look my draught is 7 meters, it says 5.5 there' and I have had to say, 'don't worry, captain, we got 3 meters of tide on top of that number'".

Another benefit mentioned was that even if you have old chart cells that have not been updated for a long time, you will get the NoGo areas based on the latest bathymetrical survey data from the area.

For pilots it is an extra confidence. It is a nice-to-have.

The service is particularly good for foreign ships not known to the area.

III.II. Procedural level

NoGo areas based on the most current surveys and for the correct tidal situation will make it easier for the VTS to show to vessels that they can actually go a certain way and they will not ground.

It might lessen the workload for the VTS because they might not need to answer the large number of questions usually received about the present tidal level.

III.III. Functional level

NoGo areas should be delivered automatically along the future route of the ship with right times for future positions along the route.

There should be an alarm for track leading into NoGo areas.

III.IV. HMI level

Several participants agreed that the NoGo area service, in the present stage of development, was too difficult to handle. It was too many clicks and too many windows to get it to work.

"But, off course it was because they were new to the system. It felt a lot more comfortable the second day than it did the first" (comment by one of the captains).

There was also a comment about the color; it needed to be more noticeable.

III.V. Survey

The participants were asked to summarize their impressions about the service in a survey with three questions (the available answer options are seen in Figure 7):

1. What is your opinion about the tested NoGo area concept?
2. Do you think a similar NoGo area concept will become reality in the future?
3. What is your professional opinion about the system tested?

Two participants had to leave early and did not take the survey. The result of the 9 remaining participants can be seen in the diagrams in Figure 7.
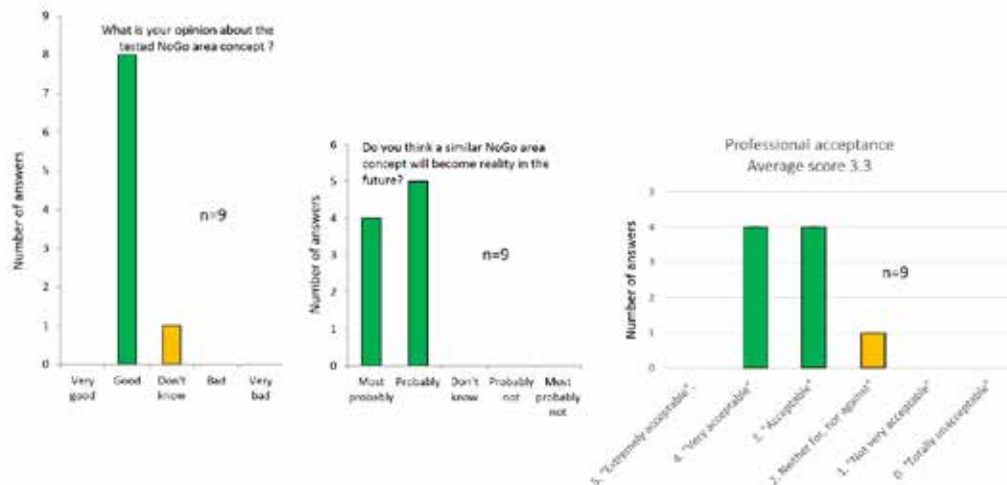

Figure 7. Results from the survey conducted after the simulation tests.

IV. Discussion and future research

It was interesting to note that some of the pilots, which had a high degree of local knowledge, was pointing out that the NoGo areas would be beneficial. The experienced pilots already have a mental model of the tidal situation in the Humber River. They

know where the vessel can freely move at the present water level. But the rest of the bridge team can by the NoGo service easily share the same mental model.

It was also obvious from the tests that further development on the HMI is necessary. Mainly this is due to the limited bathymetrical database available and the time-consuming computation of the NoGo areas. During the discussions, it was clear that the participants wanted the NoGo area to be easier to start, and should be generated automatically along the route in front of the ship. Such a time dependent NoGo area could look something like the suggestion in Figure 8, where each segment represent 30 minutes into the future from the ship's present position and time to the far right in the chart.

Figure 8. A time dependent NoGo area might look something like this. It is generated automatically in front of the ship and does not only take ships draught into consideration, but also the tidal situation at a particular point along the ships future route at the time the ship will be there. The time segments could for instance be 30 minutes.
Source: Illustration Thomas Porathe.

The Humber River and Estuary is a pilotage area, that means that there will always be a pilot with local knowledge on board bigger ships unless a bridge officer on board has acquired what is called a "pilot exemption certificate" (PEC)– mean he has enough local knowledge to conduct the ship without a pilot on board. Several of the participants mentioned that the real benefit of the dynamic NoGo area service would be for foreign ships in areas where there would be no pilot on board.

V.   Conclusion

The NoGo area service was found relevant and professionally acceptable by the participants testing the application. As The Humber is a pilotage area, a pilot or an officer with pilot exemption certificate well acquainted with the local conditions is always on board. Still the participants found the NoGo area service useful for sharing information about the ships potential maneuverable space with the rest of the bridge team.

However, the service still lacks in usability and needs further development. The service must be easier to initiate and should automatically display NoGo areas along the ships future track.

Acknowledgements

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