

## **The future of Maritime Autonomous Surface Ships (MASS) Navigation**

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### **Introduction**

The maritime world is changing, and the impact of new technologies to allow for reduced manning onboard vessels, leading eventually to unmanned large ships has taken huge steps forward over the last decade.

These vessels utilise powerful onboard processing and software to read, interpret and fuse sensor data together, typically from AIS, Radar, Cameras, Lidar and align this with historical onboard data about the world around them (typically traditional electronic static charts). They create a digital world model and make decisions on safe navigational routes that not only comply with COLREGS but also move them towards their end goal or destination.

As MASS become larger and start to tip into the regulatory landscape and can truly operate without a “human in the loop”, one area of concern is the navigational data that is required to “drive” a MASS or more importantly the lack of any stated rules, regulations or standards relating to navigational data in a MASS.

It is important here to describe what we mean by autonomous, as the term is often used to describe several modes of operation. The IMO has defined 4 distinct degrees of autonomy as shown below (note the IMO defined these degrees for their MASS scoping study and these terms may change in the future):-

**Degree one:** 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.

**Degree two:** Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.

**Degree three:** Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.

**Degree four:** Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

### **Definition of the problem**

Whilst shore based controlled vessels (degrees two and three) can use traditional navigational data such as charts and publications due to the human in the loop, the fully autonomous vessel (degree four) can't operate with these traditional products. Whilst MASS will become self-aware and use sense and avoid technologies, these vessels will still need navigational data to get from A to B or avoid dangerous or regulatory areas or operate differently when entering a specific area (e.g. Ports, Environmental Protected Areas, MARPOL boundaries, routes). To suggest that MASS will use digital ENC data in its current form is inappropriate for the following reasons:

1. ENCs (or any electronic chart) are still fundamentally designed to be viewed and interpreted by a human being and they are used to inform the mariner and help him/her make decisions based on the chart information, their knowledge and what they see out of the window.
2. A lot of ENCs are derived or constructed using traditional Paper Charts production techniques or ENCs are derived as a result of Paper Chart production, and as such inherit subjective cartographic practices (such as data generalisation or aggregation) and therefore may only represent “ground truth”.
3. ENCs suffer from data inconsistencies (i.e. features aren't always on charts that cover the same area at different scale bands, usually as a result of cartographic practices), which a human can identify and resolve.
4. ENCs suffer from horizontal inconsistencies (i.e. edge matching one ENC against another can highlight differences, usually as a result of cartographic practices), which a human can identify and resolve.

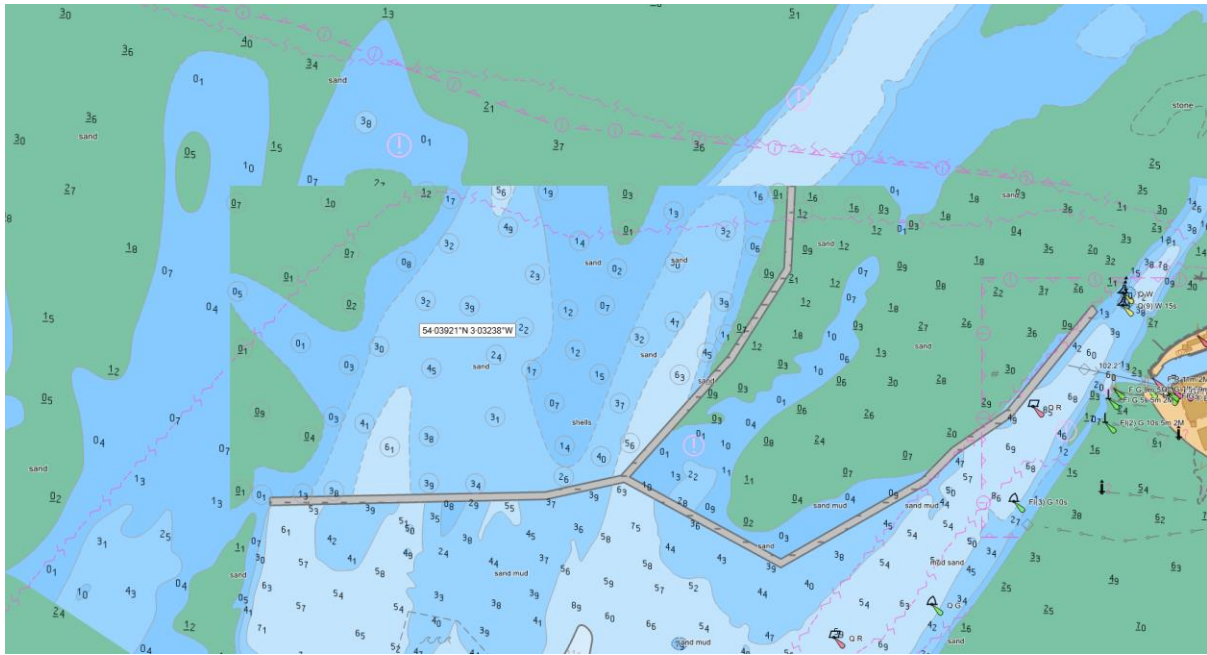
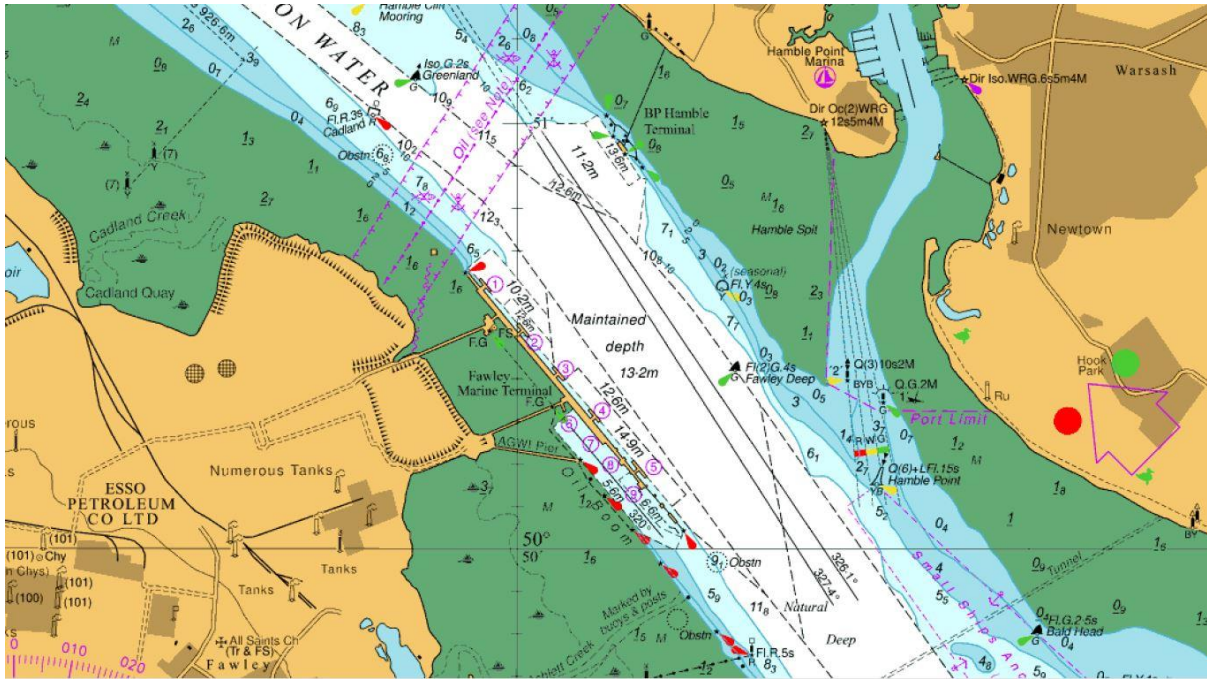


Figure 1: Example of horizontal data inconsistencies with two ENCs covering the same area at different scales.

Current navigational practice relies on personnel being trained in safe operations of vessels, gaining experience and working their way up to the point of taking responsibility on the bridge. They rely on their eyes to look out of the window, their ears/balance and stomach and the ships sensors such as radar and AIS. They formulate a picture or situational awareness in their head, align this with a chart and physically read with their eyes information on approaching hazards or navigational instructions on the chart. They then formulate decisions on changing heading or speed. Over hundreds of years the information provided on nautical charts, radars and aids has been optimised for the human to read. Too much information and things become cluttered and information missed, too little and richness of picture is lost.

### Contextual information

A perfect example of this is the textual information used in text boxes on charts. This information isn't pictorially or geographically portrayed on a chart as it could lead to clutter. However, this textual information often describes restrictions or constraints in passages of water in which the mariner must read, understand and then modify the way he/she drives the ship to conform to these rules. This text is worded in a way that humans can read and digest, however, it is not machine readable, nor does the description of the area in question conform to strict geographic locations. In the example below (Figure 2), how would a MASS conform to the rules underlined in red and take into account the locations shown in green. Note that these areas are not shown on the chart and that the text is not consumable by a machine.



**10. Speed Regulations:** Consistent with safe navigation, vessels drawing 6.0m or over must not exceed a speed over the ground of 7 kn when approaching or passing the Fawley Marine Terminal, or the BP Hamble Terminal. Other vessels should not pass the terminal at excessive speed. Vessels passing the Fawley Marine Terminal and the BP Hamble Terminal should not navigate closer than 130 m from the face of the jetties in order to protect vessels alongside, to guard against the interaction between vessels and to prevent the risk of naked lights within these areas. There is a speed limit of 6 kn in the area north of a line joining Hythe Pier (50°52'49N 1°23'60W) and Weston Shelf Light Buoy, 3 cables NE.

Figure 2: example of speed restrictions in Southampton

#### Filtered and generalised data

Furthermore, to make charts and in particular, bathymetry, easier for the mariner to read we filter the high-resolution survey data so that we do not overwhelm the mariner with a cluttered view. Indeed, it is the art of cartography in removing information whilst leaving just enough to allow the mariner to use the charts safely and make sensible and safe navigation decisions. To illustrate this idea, the process and diagrams below illustrate how we filter rich data to create a picture of the seabed that is presented to mariners

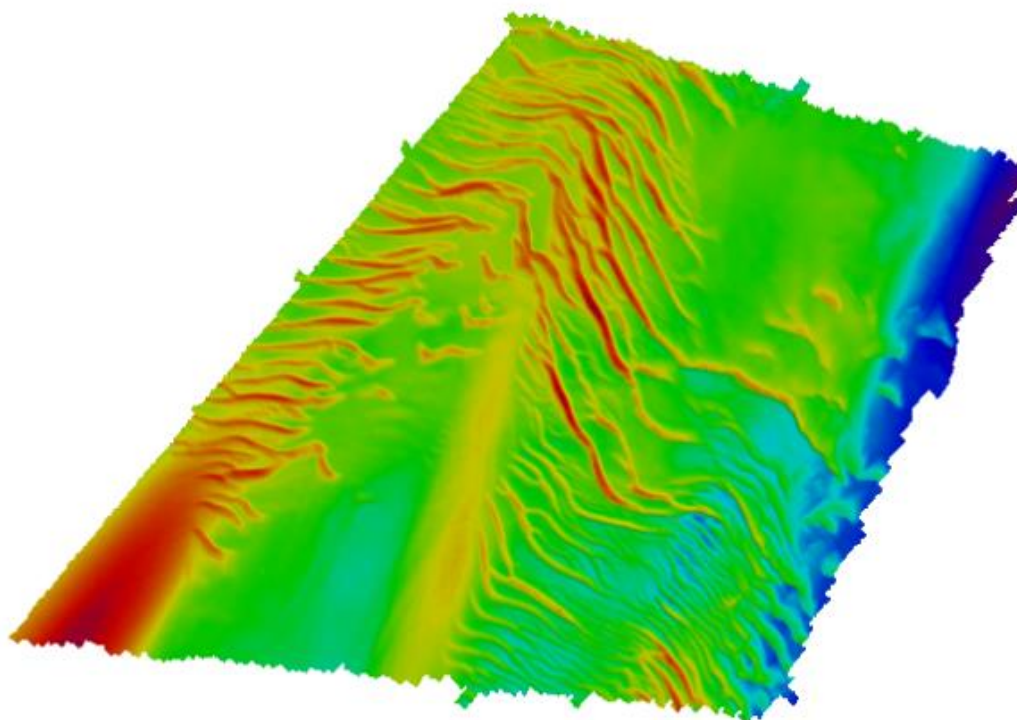


Figure 3: This diagram shows the Thames Estuary from a multibeam survey surface.



Figure 4: Thames Estuary multibeam survey is then turned into a sounding selection by a trained cartographer (in this case at 1:50000) and the data is heavily filtered to achieve this





Figure 5: The sounding selection is then turned into depth contouring at standard interval (further filtering of data).

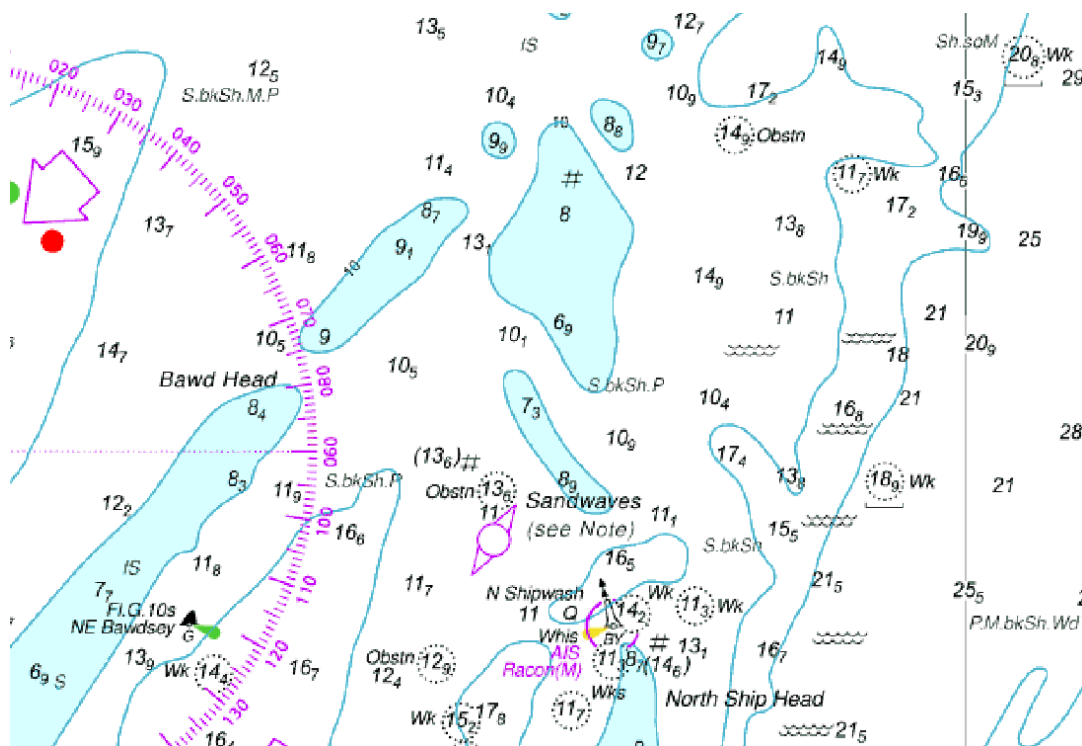


Figure 6: The contours are then further generalised by cartographers to make the charts (paper and digital). As can be seen, the result is an uncluttered and deconflicted cartographic representation of the real world, but isn't the real world and still needs to be viewed and interpreted by an experienced and qualified mariner.

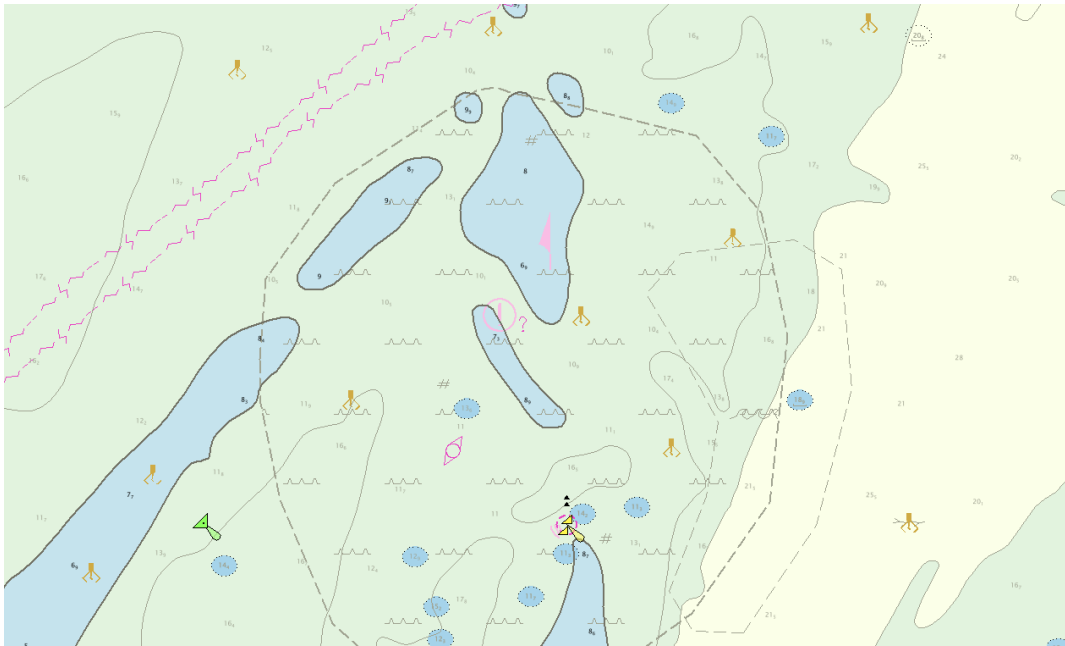


Figure 7: This is the ENC of the same area, and in most cases is a direct copy of the paper chart and so inherits the cartographic subjectivity that is present in the paper chart and still requires human interpretation.

### Position fixing

It is expected that MASS will have a dependency on GPS to know where they are at any given time and make navigation decisions in relation to other objects to avoid or sail towards. However, what happens when a fully autonomous vessel loses or is denied a GPS signal or is subject to GPS spoofing. What alternate means of positioning can be used by a MASS and therefore how can the data we supply help in this situation. Something new and different to what we supply today is needed to resolve this issue.

### Updating of chart data

Clearly whatever navigational services are required by MASS, the crucial aspect of maintaining and updating the data is as important in an autonomous environment as it is in today's manned shipping environment. Indeed, today the maintenance and updating of charts and publications is a SOLAS requirement and should follow suit for MASS. That said, the current process for updating products (digital or paper) is based on a weekly update cycle and in some cases vessels wait for a CD or DVD to be sent to the vessel to update their ECDIS and Back of Bridge PCs with data. This builds in a delay between products being updated and CDs or DVDs being distributed and vessels receiving the updates to install on their ECDIS, in some cases this delay can be several weeks if a vessel is away from port for prolonged periods. Some vessels do elect to download product updates from the internet, however, due to satellite communications being expensive at sea, this is limited to the wealthier shipping companies. To compound this issue most shipping companies restrict their vessels to a 5mb download limit. However, updates can often be much larger, particularly if a vessel has a large portfolio of ENCs and associated products.

So the question is, what does that new next generation navigational service/s look like for large ocean going MASS?

### Potential future solutions

The UKHO is beginning to explore some potential solutions to the issues mentioned above and is working with the MASS industry and community to explore what the next generation of products and services will need to look like for large ocean going MASS.

An unmanned vessel will need to make navigational decisions within a detailed, constantly updating digital world model that is a combination of known / historical data and calculated results from live sensor feeds. The richer

the static and dynamic information the more complete the model and the safer the navigation will be. The potential exists for significant quantities of data to be re-introduced to the navigational systems. MASS could easily consume this rich data without fear of overload and this would present a ground truth of the surface of the seabed to avoid the risk of grounding or collision. Therefore, a likely solution is the introduction of high-resolution gridded bathymetry in a single surface model giving a true picture of the seabed (see Figure 8). Indeed, this could even be used as an alternative means of positional fixing and some experimentation has been done in this space, drawing on the methods employed in submarine navigation. S102 offers the potential solution to this issue.

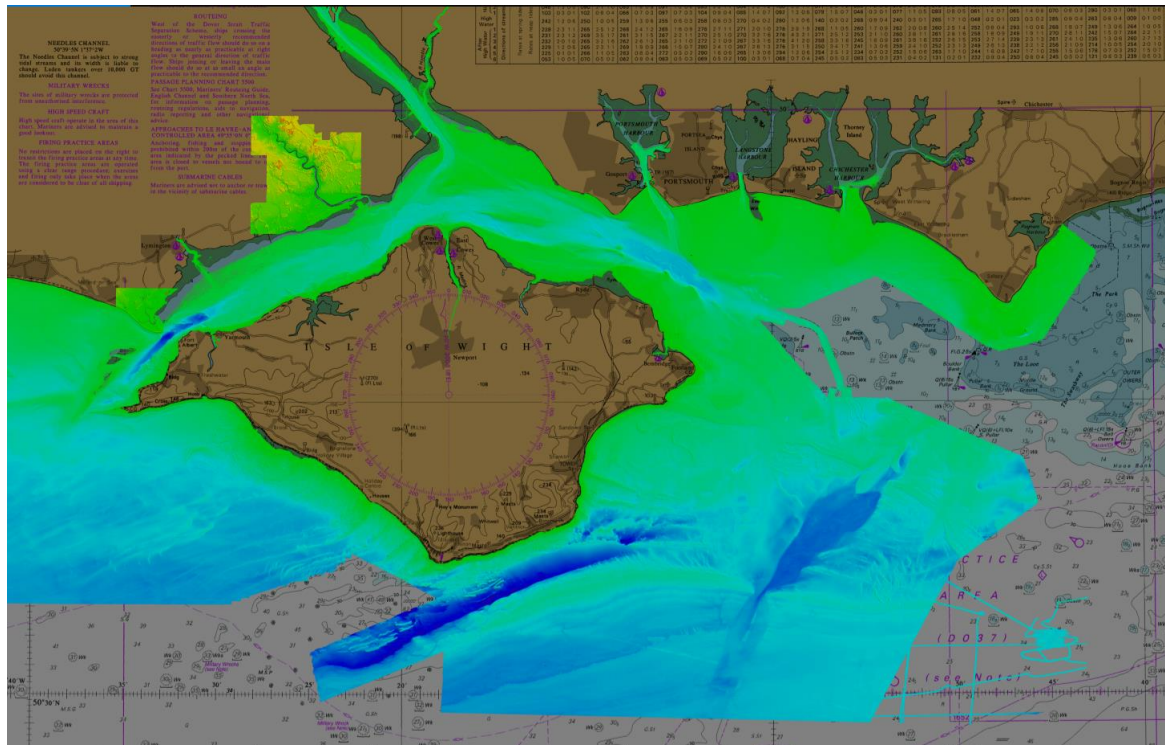


Figure 8: High resolution gridded bathymetry overlaid on a traditional SNC

### Alternate position fixing methods

With regards to alternate position fixing, a number of options exist, not least of which is using the high-resolution bathymetry as mentioned above, but to augment this, other means of positional fixing could be employed.

For example, mariners still use visually conspicuous objects on the coastline to triangulate a fix. Indeed, we highlight features in ENCs as visually conspicuous for this reason. However, another method can be employed which takes its origins from a centuries old concept. Sailing ships used to employ artists on board to paint or illustrate parts of a coastline which formed part of the chart marginalia. These illustrations allowed other unfamiliar mariners to recognise from the pictures, aspects of the coastline, in order for them to orientate themselves and work out where they were in relation to the coastline of feature.

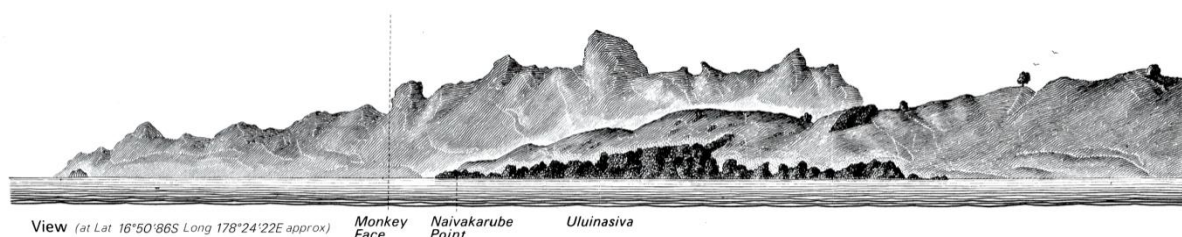
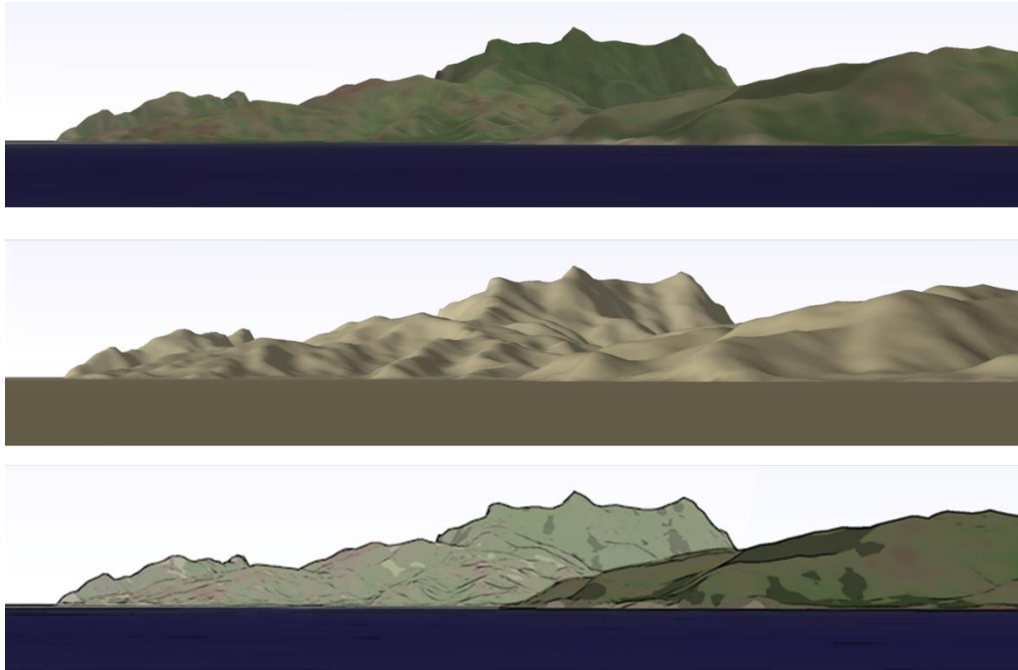


Figure 9: Example above shows original etched view of Yadua Island to Yaqaga Island (Fiji)

We carry this concept into the 21<sup>st</sup> century in that Sailing Directions have hundreds of photographs of coastal or visually conspicuous objects to aid the mariner in navigation by showing them what they can expect to see when looking out of the window.

It is conceivable to use modern technologies to provide data in a format that the MASS, using advanced optical sensors, could use to determine its position. For example, the images below (Figure 10) are a digital construction and view of the Yadfua Island.



*Figure 10: Digital model of Yadfua Island*

It is possible today using 3D gaming engine technology to create a digital model of the coastline and associated features, incorporating lighting effects and day or night views, which could be accessed by the MASS to compare the digital view compared to the view it is seeing using its sensors to then determine where it is in relation to that feature..

Furthermore, we could drape high resolution satellite imagery over lidar or terrain models to make a more realistic model of the real world that could be used for navigation, as illustrated in the image below (Figure 11).



*Figure 11: An example of high-resolution imagery of Lulworth cover draped over a terrain model.*



Building on the above examples, Digital Twins are a logical evolution in the marine domain. Digital Twins are a digital replica of a living or non-living physical entity, which can interact with the real world or simulated world through sensor feeds or software interactions. The Digital Twin concept has been used throughout the autonomous automotive industry for some time for driverless car technologies and therefore, it is highly likely that Digital Twins of the coastline, port environment and wider marine environment could be approaches that becomes the new digital norm for MASS navigation.

The above examples and concepts are excellent when in close proximity to the coastline, however, in deep ocean waters, this will not be useful. Concepts such as astral navigation is a possible alternative for open ocean navigation and as technology improves this should become a viable alternative to GPS if the need arises. The UKHO will be conducting a number of research and development projects this year with Her Majesty's Nautical Almanac team (based at the UKHO) and academia to determine the art of the possible in this space.

### Additional navigation layers

We should start to capture the contextual text information (mentioned above in Figure 2) as additional geographical layers to allow the MASS to look ahead, determine if it will encroach into one of these areas and modify its behaviour accordingly. The example in Figure 12 is a concept of how the restrictions in Southampton could be captured as geographic polygons with appropriate attribution to allow for interrogation by a MASS's navigation system to determine how it should behave i.e. in this case avoid or throttle back.

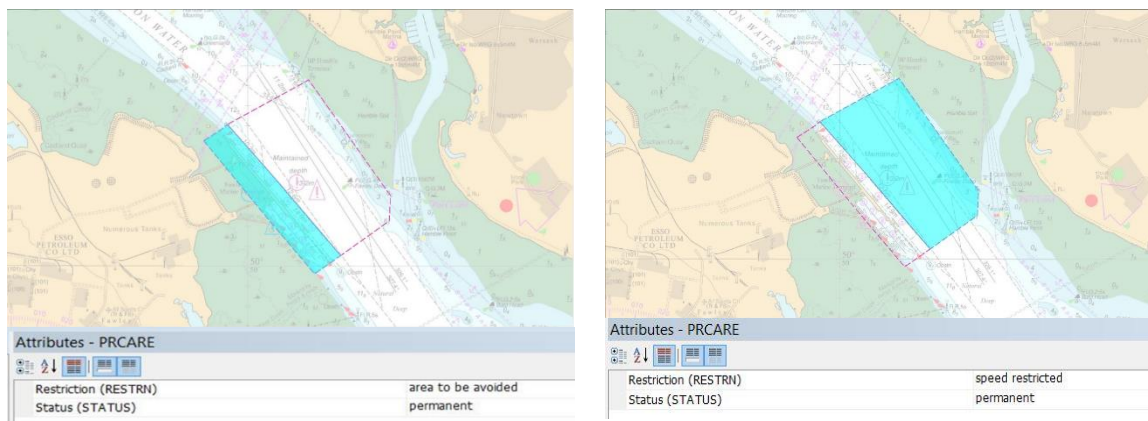


Figure 12: Example of capturing contextual information such as restrictions as geographical features

### Always on and listening for updates

In the world of MASS, it is expected that communications between the vessel and shore will be on at all times and as such this could enable more frequent or real-time updates to be pushed from official sources from the Hydrographic Office community. The vessels "listen" out for and update their navigational database and products automatically irrespective of where they are in the world. This would be an advantage over the current situation in the manned shipping environment, however, thought would need to be given to prove that a MASS has indeed got the latest available update and applied it. Today that function is carried out by mariners and confirmed by Port State Inspectors. An equivalent model will need to be defined and used to provide the assurance that the vessel is up to date and conforming to SOALS regulations with regard to navigational data and situational awareness.

### Impact of S100 on autonomous navigation

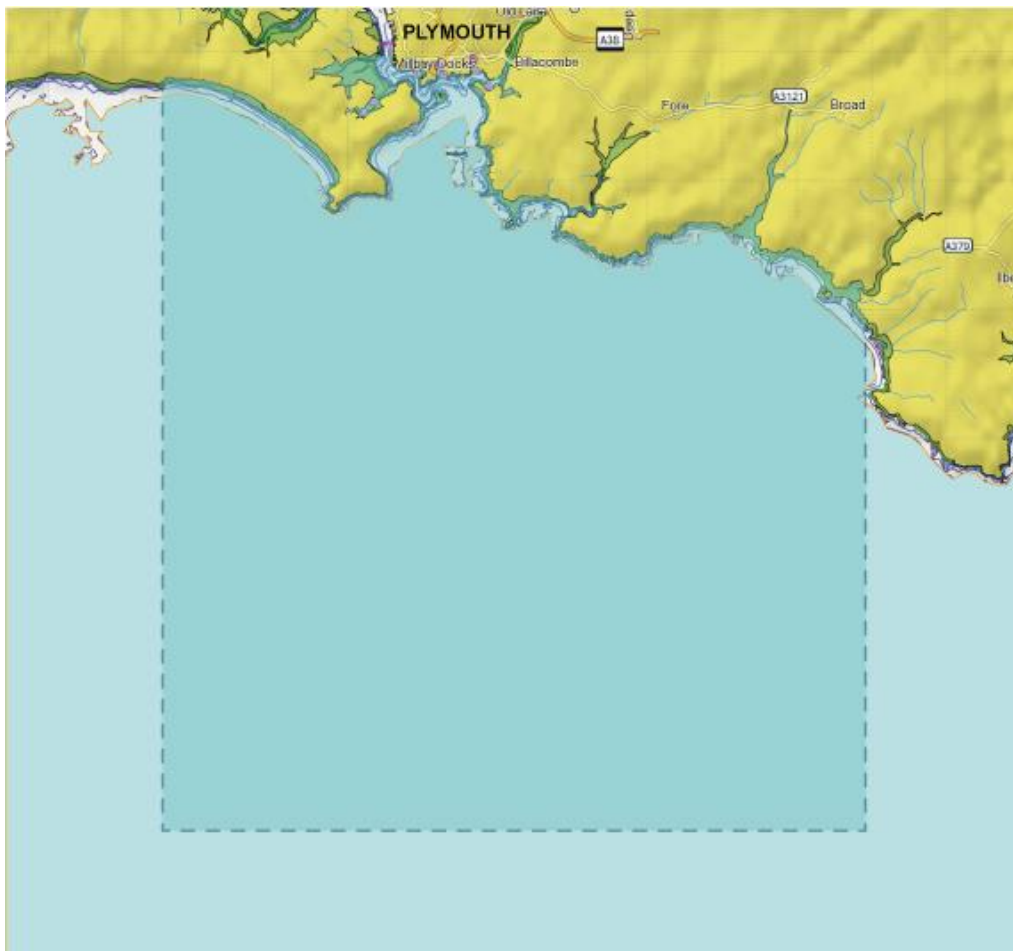
Although S100 and the associated product specification (S1xx) series of standards represent a significant step forwards at present they are still in relatively early stages of development and are being designed with a human end user in mind. It is estimated that the S-101 product specification (next generation ENC) will not be available for operation until 2022. Although there is no question that in principle this is an excellent concept the timescales to which it is delivered remains to be seen. At present the S101 implementation will make minor improvements to S57 however there will be no significant improvements regarding making the data more machine readable than is currently possible with S57.

The main benefit of the S100 framework is that it is extensible and therefore the data model can be adapted as new requirements emerge. However as demonstrated by the relatively slow development of S101 (for various

reasons) these changes are unlikely to be made quickly. It is vital that these future requirements are considered now to ensure MASS are able to utilise the data produced by hydrographic offices around the world.

### **What have the UKHO been doing**

The UKHO has been engaging a number of industry experts and project initiatives surrounding MASS to try and understand the navigation data needs as momentum gathers in this area. That said, we have found that these organisations are using traditional navigation products (such as ENC's and even paper charts) and working round the limitations that have been described above. In most cases, the people who are building these vessels and the systems used on board, don't know what they don't know, in other words they aren't aware that they need something different and don't know who to ask when they need richer data. For example, I have seen examples of people trying to reverse engineer S57 contours into a 3D terrain model and mission planning systems using Google Earth. To that end we have proactively sought out a number of organisations such as Thales and TGP Polaris and discussed the issues with current products and services and have provided data to stimulate discussions about what they see as gaps in the current offering and identify the new products going forward. We have also been supplying data into two key projects and associated geographical areas where MASS trials have been conducted (though it is important to note that the MCA is supporting MASS trials anywhere in the UK with the right certificates and approvals). These two areas are the Plymouth Smart Sound area (Figure 13) where we are part of the Future Autonomous at Sea Technologies (FAST) cluster and the MCA's MARLab (Figure 14).



*Figure 13: Plymouth Smart Sound area for MASS trials*

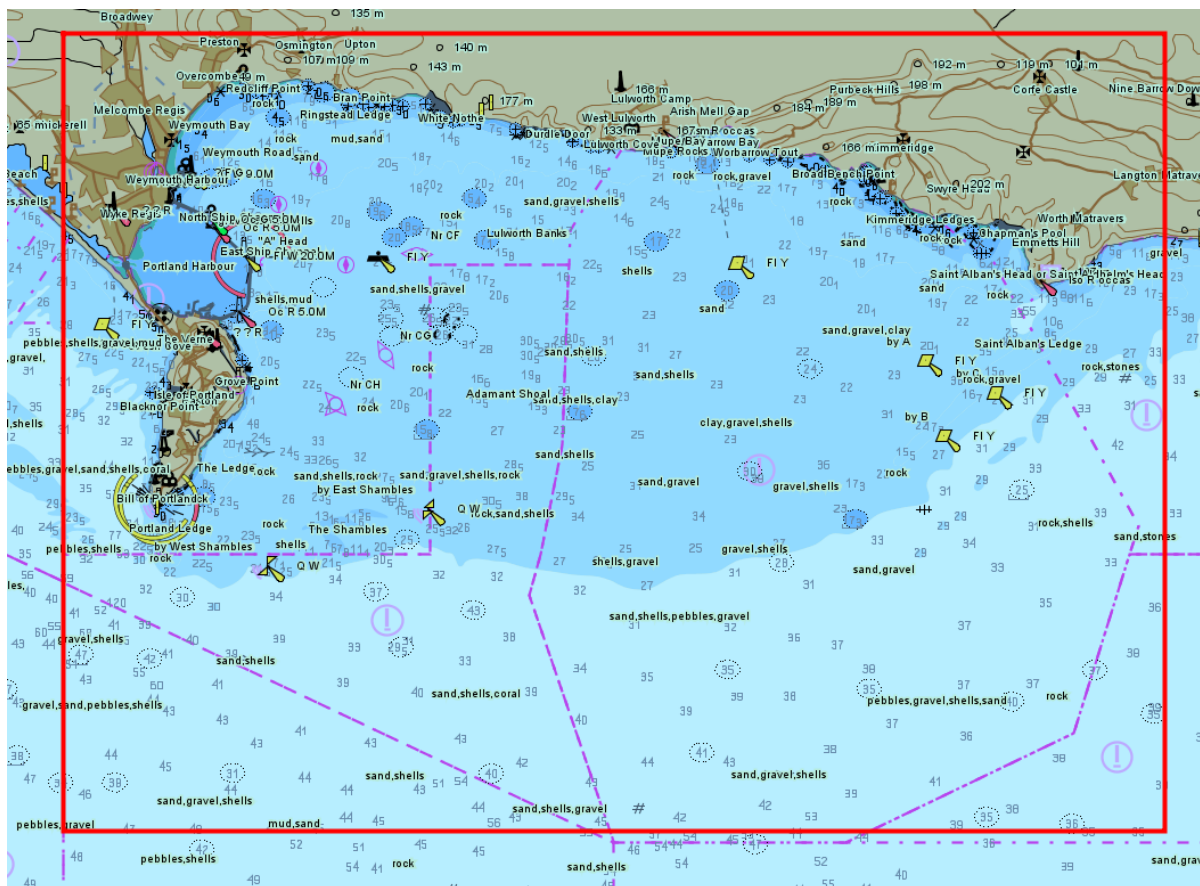


Figure 14: MCA's MARLab are of interest centred on Portland Harbour

In both instances and in our work with industry operators, we have supplied the following data to facilitate discussion and allow operators to explore what the future navigation service might look like.

- High resolution Bathymetry surfaces (2m resolution)
- Access to a tidal prediction API
- Unencrypted ENCs
- Environmental Protected Areas
- Wrecks
- Cables
- Anchorages
- Contextual Information from SDs (restrictions, constraints, speed limits etc)

### International collaboration

Whilst the UKHO has been exploring some of the concepts above, due to the international nature of shipping the problems outlined above are also an international challenge. Whatever the future looks like for navigational data for unmanned ships, the problems above can only be solved on an international level. No one state can produce and define its own approach to navigation services, ultimately the solutions must be governed by international standards and mandated by the IMO. The International Hydrographic Office community should therefore start to work together to address these challenges and start to look ahead and build and test the concepts now, as the MASS industry and developments within it gather pace. In short, we need to be ready to support the transition from manned vessels to unmanned vessels and work collaboratively in doing so to ensure that the future of navigation remains safe. I therefore pose that it is the right time to set up an IHO working group for MASS navigation to ensure a collaborative and joined up approach is adopted and to start to define the new standards for MASS navigation?