MASS Nav PT Work package 2-6 report template

Member State:

WP2: Identify and report what test bed activities are happening in each member state's region and which degree of autonomy is predominantly used.

There's significant activity happening in the UK covering the full range of MASS Degrees. That said, it is fair to say that most of the vessels being used are smaller craft which fall into the MCA's workboat description, though there are a few developments happening with Ocean Infinity and Promare which will see vessels being developed way over 24m in length.

There are two main hotspots of activity in UK waters (though the testing of MASS can happen in any part of the UK waters with permission from the MCA and local Harbour Maters). The first area is based in the Plymouth region, which is known as Plymouth Smart Sound (https://www.smartsoundplymouth.co.uk/). The Smart Sound area covers approx. 1,000 sq. kilometres of authorised and de-conflicted water space that is used for the trials, validation and proving of marine innovative technologies, with an emphasis on marine autonomy. Furthermore, there is a cluster of autonomous vessel operators, builders, system integrators and academic institutions known as the Future Autonomous at Sea Technologies (FAST) cluster that operate and use the Smart Sound (https://smartsoundplymouth.co.uk/Industry). UKHO is a partner of this cluster and engages the members on aspects of navigation relevant to MASS.

The Solent is another hot spot of activity with a number of MASS developers operating from the area around Southampton and Portsmouth. The UK's National Oceanographic Centre with its Marine Robotics Innovation Centre being one of the main players in the Solent area along with world leading players such as Ocean Infinity and their new Armada fleet, L3 Harris and Atlas Elektronic.

One of the most high-profile MASS projects is the Mayflower Autonomous Ship (https://mas400.com/). The Mayflower Autonomous Ship (MAS) is an initiative led by marine research non-profit Promare with support from IBM and a global consortium of partners. It can spend long durations at sea, carrying scientific equipment and make its own decisions about how to optimize its route and mission. With no human captain or onboard crew, MAS uses the power of AI and automation to traverse the ocean in its quest for data and discovery. The ships' AI Captain performs a similar role to a human captain. Assimilating data from a number of sources, it constantly assesses its route, status and mission, and makes decisions about what to do next. Machine learning and automation software ensure that decisions are safe and comply with collision regulations. The UKHO has been involved and continues to be involved in a number of MASS navigation projects with the Promare team using the Mayflower as a platform, which will be outlined further in this report.

It is also worth reporting that Warsash Maritime Academy, which is part of Solent University Southampton, has just established the Warsash Maritime Autonomous Surface Ships Research Centre. The Warsash MASS Research Centre (WMRC) aims to develop into a world-class 'Centre of Maritime Excellence' and become an international leader in maritime research. The centre will explore the future possibilities in developing MASS technology and study the impact of these innovative technologies on human elements while working in tandem. The centre will also explore the pedagogical, professional education and training needs to make the workforce future-ready to operate with these technologies either onboard MASS or remotely from shore stations.

WP3: Report on what data MASS operators and MASS navigation systems are using today in each member state's region.

Due to the nascent nature of MASS, the industry is trying to make do with traditional products and services that are used by manned vessels. We have seen examples of Google Earth used for planning MASS missions, paper charts hung on walls for situation awareness and unofficial charts and publications being used. The more advanced operators are using S57 data, despite some of the limitations of the data. In our discussions with MASS operators the main focus to date has been on implementing sense and avoid technologies using computer vision, radar and AIS, little thought has been spent on the navigational data if at all. That said, those that are using traditional products and services, such as S57 and Tidal data have expressed a number of limitations and issues with these traditional products, some of which may still be present in the new S100 framework as the primary use for S100 is still an ECDIS and human being.

The issues encountered have been outlined below: -

Sonardyne:- They don't make MASS but do make INS equipment for manned and unmanned vessels, their flagship product being the Sprint NAV which uses doppler log technologies. They spoke of a number of projects where they want to use their INS coupled with terrain following capabilities to act as an alternative positioning system for GNSS denied or spoofed situations. However, they talked about not wanting petabytes of bathymetry data and were interested if significant seabed features could be categorised for INS systems to lock onto. This is a similar construct to land based visually conspicuous features only on the seabed and the feature could be obstacle and pinnacles or even trenches.
Furthermore, they were interested in the reflective nature of the seabed could also be categorised, which is useful in the technologies they use in the INS systems. Whether this could be derived from the seabed characteristics or not is something to be determined (i.e. is sand more reflective than rock). They also were interested in modelling acoustic qualities as some of the INS systems struggle in waters with poor sound qualities.

BlkSail:- their decision support system is capable of Degrees 1 + 2 currently with plans to go to degrees 3 and 4 in time. The biggest issue they face is the scheming of charts and edge matching issues when moving from one chart to another, often with discontinuation of data (contours and depth areas being an obvious area of data discontinuity). They describe a "leap of faith" when moving from one chart to another. Humans can make this leap easily, but computers find this an issue. A number of solutions could be provided here, one could be to have seamless and scaleless data for MASS, another could be a consistent gridding approach and another could be some method of describing what is happening at a chart edge if there are data discontinuity issues, or even allowing overlap of data to allow for continuity.

They also desire more visually or radar conspicuous features to be captured which can be used to triangulate a position in a GPS denied environment. That said, there need to be some form of attribute that describes the certainty of a features' position. Some features are immovable (e.g., lighthouses) whilst some features can move (e.g., a buoy), so having a sense of how certain a position is will be crucial for systems trying to auto triangulate itself.

They also want the main shipping lanes to be made available. HO's typically steer away from showing these due to clutter, but this may be crucial information for MASS.

Tidal heights and surface currents are also important for under keel clearance. They need predictions and forecast tides and surface currents, but again certainty factors surrounding the predictive and forecast heights and currents is very important. They suggested having a percentage factor (e.g., 80% certain the tidal height at this location and time will be 3m).
The temporal nature of data is also of concern. Data always being as up to date as possible is paramount, the example given was for seabed areas that are dynamic in nature or highly mobile. There may be a need for an expiry date on the data, or as mentioned above a certainty factor could also help in this regard and help the MASS make decisions based on certainty factors and risk.

MASS operators are tending to use a combination of existing data supplemented in conjunction with sensor inputs, namely AIS, conventional and IR cameras, radar.

ASV (now L3 Harris) – UKHO conducted a report into the future of navigation for MASS for the UK Govt Dept for Transport utilising the Transport – Technology, Research and Innovation Grant process. Some of the key findings from that report (which will be referred to as the T-TRIG report), are outlined below.

Computer vision and visually conspicuous features and imagery
Vision, or 'what is out of the window' is without doubt one of the most important elements to situational awareness. Monitoring dynamic objects, identifying static objects, confirming position relative to the coast or navigational marks, monitoring the weather and sea-state are all critical to safe navigation.

The performance of these visual systems is heavily dependent on large training/reference sets of images and databases of the coastline/navigation marks.

Despite a notable absence from the primary working document of the modern navigator, imagery provided for illustrative purposes still plays an important role in navigation and is featured extensively in coastal 'pilot' books, port familiarisation and approach guides, Sailing Directions as well as some electronic chart displays.
In addition to still photographic images, larger vessels with more stringent safety requirements may also provide on-board simulation facilities that allow bridge crew to rehearse harbour approaches and docking manoeuvres in a synthetic environment; utilising detailed 3D models that capture both the underwater and the above-water environment.

All these documents and systems work together to help the mariner build up a mental model of the approaches to a port, supporting situational awareness, planning, and overall helping to ensure safe operation in these congested waters.
Looking forward, the use of synthetic and photographic imagery by human mariners seems certain to increase substantially, driven by both advances in technical capability and expectations set by the availability of consumer information services such as 'Google Street View'.
As an example of the art of the possible, the 'Chart of the Future' research programme funded by the US National Oceanic and Atmospheric Administration (NOAA) and carried out at the University of New Hampshire has shown the potential of panoramic photographic imagery integrated into electronic navigation tools and illustrated the benefits that it can provide to mariners in reducing cognitive load and improving safety.

Autonomous surface vessels have a rapacious appetite for imagery data and consume it in industrial quantities. However, unlike imagery intended for the human mariner, this data is not destined for the masters of individual vessels, and nor is it (only) consumed at sea, but rather it is also exploited on land by the engineering process which produces and maintains those vessels.
Almost every stage of the product life cycle has the potential to consume imagery data.
The first demand for non-trivial quantities of imagery data arises from the development and training of the learning algorithms which are typically used to detect and classify potential hazards in the waters around the autonomous vessel.

With systems in service, the need to maintain that assurance against the background of a continually evolving and changing world will raise its head, creating a potential need to keep simulations up to date with real world conditions and to identify incipient risks and hazards.

It is likely that systems for navigating harbours and inland waterways will operate in a similar fashion, making use of detailed three-dimensional maps or Digital Twins, built using a combination of Lidar, radar and camera sensor data. These maps enable high precision manoeuvres and help to counter the possibility of malicious GPS spoofing attacks.

These are entirely new data flows, ones which challenge our preconceptions of the role of charts and of the role of maritime geospatial data and of how we might use these things to assure the safe operation of vessels at sea.

This imagery could include but not be limited to:
- Coastal terrain (possibly from several offset distances with the camera height carefully recorded)
- Navigation marks
- Harbour approaches
- Dock / quay walls
- Major buildings or landmarks
- Bridges and other man-made structures extending out to or over the water.

Another significant element of potential for navigation is the integration of 3D coastal imagery, and recent work looking at Digital Twins of the port or coastal environment could offer much potential as a navigation tool.

Contextual data found in text boxes or Nautical Publications
The amount of information that can be placed on human readable charts is limited. It is typically graphically represented with side information notes and if too much is added the chart becomes over-cluttered and information can be missed. The situation for an autonomous system is vastly different, a computer can handle very complex, multi-layered information sets with ease and therefore opens the potential for significantly more information to be included. These need not be limited to simple graphical representations but can be defined co-ordinate geographical 'fences' with logical machine-readable instructions for actions.

For computer-based systems, reading in data sources like these is particularly difficult due to the complexity of the retrieval of the data and its need for interpretation. As a human looking at a chart it is relatively easy to understand information like coloured buoys marking the edge of a channel, but for a computer linking these buoys correctly to form a line and thus a channel can be non-trivial. With information like this in a suitable format for autonomous and smart vessels to understand, it makes it possible for them to plan paths and obey the rules of the sea. Instructional layers are going to be a method of supplying a smart or autonomous vessel with this information, in a way which it can successfully interpret, enabling it to make safe and sensible decisions.
The aim of instructional layers is that they are a machine-readable set of data, where location-based information can be accessed. The instructional layers would contain a location, identifying name, description, unique number and any additional information.

Before departure this information will allow for more sophisticated planning as information like speed limits in areas will be available to the software when it starts calculating a passage, enabling it to arrive on time at its destination.

The data contained will be of a factual nature, rather than offering guidance. An example of this would be a zone identifying a natural kelp bed. It is then for the autonomous vessel to decide if it can safely traverse this area or not. This allows the vessel to make use of on-board sensors to identify the depth of the kelp, which will be seasonally dependent, rather than being instructed to avoid and area due to the possibility of kelp tangling in the vessels' propellor blades.

Accurate depth mapping could also be useful for an autonomous vessel as a navigational aid, beyond the basic calculation of if the vessel can safely traverse an area. Navigationally, the depth recorded by the vessel can be used to identify a likely current location, and thus can be used as a secondary source of positioning data.
Extra information for a depth instructional layer would be the material of the seabed along with the uncertainty for the depth. For soft seabed materials, like sand, the depth can change significantly. This makes the depth measurement inaccurate, and for an autonomous vessel it would be helpful to have an indication of the variation observed within the area, and thus an error in the measurement. For a rock-based seabed, the depth will not change, thus the error in the depth measurement would be minimal.

Speed limits are another area that would work well for instructional layers. They would be larger polygons identified by longitude and latitudes marking the vertexes. These would simply specify the speed limit within the given area, e.g., within a port. By having this information digitally, the vessel is not expected to be able to identify and 'read' speed signs on a harbour wall, making obeying them a simple procedure. An autonomous vessel would be aware that its planned path would pass through a speed limited zone and could plan its passage to adhere to the limit, whilst still reaching its destination on schedule. Including information like the reason for the speed limit may also help an autonomous vessel make educated decisions. For example, if the speed limit is a temporary limit around harbour works the autonomous vessel may plan to totally avoid the area as there is a higher risk collision with working vessels.

Communication zones would be of particular use as currently the rules for radio communications are within the Admiralty list of radio signals volumes 1-6. These volumes are particularly difficult for an autonomous vessel to understand.

National infrastructure zones would also be necessary to identify areas of importance which could have security implications. For example, undersea pipes which transport oil and gas may be marked approximately on a chart, but the exact locations are not displayed as they supply an important service that could be maliciously targeted. For these areas a polygon larger than the infrastructure would be used to obscure the exact location of the resource, and thus protect it.

For each instructional layer/feature there would be a list of longitudes and latitudes connected to form a polygon. There would then be a list of attributes for the polygon, containing the information the vessel needs to act correctly within the area.

Most of the layers/features will be for permanent information, but it would also be possible for temporary layers to be added, with vessels receiving this information as they enter a port. These layers may include the time and path of a cruise ship leaving port, or a temporary exclusion zone around a dredger. This type of temporary layer is most likely to be controlled by harbour masters, containing information that they would typically disseminate to captains. Navigation warnings could also be added to temporary instructional layers, as they contain a location and information about that area. This then allows autonomous vessels to use the most current information during its passage.

Unique Identifiers
A chart may show an area of 'mooring posts' but not define how many or where, this information would overload a human readable chart. If, however they were identified with unique ID numbers and positions in a machine-readable format they would be a highly accurate method of the MASS in verifying its position, progress against goals and navigational status.

Updating data
In the world of autonomous vessels, it is expected that communications between the vessel and shore will be continuous, uninterrupted and as such this could enable more frequent or real-time updates to be pushed from official sources (such as the UKHO) that the vessels can 'listen' out for and update their navigational database and products automatically irrespective of where they are in the world. Event driven data updates and near real time updates will be required for MASS.

Sea-Kit - They are using Degree 3 (i.e., remotely operated), but at the lowest end of that spectrum, all decisions are made by the human remote operator and for Degree 3 they foresee that they will still use traditional and next generation navigation products as mariners on board do today.

That said, some similar themes as mentioned in previous discussions came out. The need for very accurate data and a sense of assurance on the accuracy is key for their operations.

They also mentioned discrepancies in Tidal data (i.e., Prediction and Forecast isn't always right), so do we need to reconsider 'real time' being put back into S104 and the certainty aspect mentioned above with BlkSail?

RoboSys – Their Voyager system operates somewhere between Degree 3 and 4. The system takes in a predefined route which it will follow, but it will make decisions and deviate if hazards are detected and then come back on track. It can also aid the mariner in evaluating a predefined route and can determine if a route is safe or not.

Issues they have are accurate Tidal Height and Surface Currents (speed through water versus speed over ground is crucial). The quality of the data is vital, specifically in congested water space areas. This theme is common across operators we have spoken to.

Another big factor for them is restricted water space. The examples given included military exercise areas or firing ranges, they need to understand when these are active and associated restrictions in force. Currently, this information is not clear. The example he went on to describe was that Voyager will see that feature on a chart and recognise it as a no-go area and traverse around it (could be some distance). However, the range may only be briefly active, and the vessel may be safely transit this area at the intended time thus avoiding a lengthy detour. So, temporality of features and their use is very important for MASS systems.

They also mentioned that speed restrictions are not shown on charts which was identified by ASV in the T-TRIG report referred to above. The restrictions are often captured in Sailing Directions or text boxes on the edge of charts and are very verbose text, not really suitable for machines to read and interpret.

He also suggested free text in Nav Warnings could be a problem for machines to interpret and act upon. Indeed, we have spoken to the Chair of the WWNWS and S124 chair, and the free text aspect of navigation warning is an area that needs to be addressed.

Temporality coupled with additional attribution may also be very important. An example given was fish farms, whilst they may be marked on charts, it might be useful to know that at certain times in the season, these features need a wider berth due to breeding etc. Whilst at other times, it is perfectly safe to travel in close proximity to the fish farm.

Unsurprisingly, confidence levels in the data needs to be articulated (this is becoming a theme), specifically related to tidal heights. Bramble Bank in the UK was used as an example, where being at variance by 0.5m (shoaler) could lead to a grounding.

Another big factor for their system is knowing that the vessel needs to go through a traffic separation scheme. Voyager can pick its own route and will avoid hazards, but how would it know it needs to join the TSS when entering the English Channel? Whilst it's not our role yet to identify solutions, there are two possible options or perhaps both could be employed.
The first would be to have a constricted water space feature with an attribute that states TSS is present. The MASS can then do a spatial search within the feature for the TSS and then route to and through it accordingly. The second option is to have a buffer attribute on the TSS of say 50nm, then when a MASS route intersects the buffer, the MASS knows that it must now use the

TSS. Both used together could work, but this is a simplification and other factors such as directionality etc would need to be factored in.

The idea of a conditional hierarchy for autonomous decision making was discussed. An 'if this, then that' approach. As an example, the previously mentioned TSS's reporting points and speed limits are relatively fixed so are high up within the hierarchy, other temporal features are not and can be further down the hierarchy. Furthermore, "if, then, else" type parameters could be used for temporal features such as active gunnery ranges requiring specific action during the active phase (e.g. if feature is a range and it is active then avoid, if not active else safe to pass through).

Reporting points also need to be made available spatially with appropriate attributes. The example they gave was knowing at what point to contact Falmouth Coastguard to say whether you were passing between UK mainland and the Isles of Scilly or not.

A generic comment from Market Research carried out by the UKHO suggested that dynamic areas of restriction would be really useful, these are not on charts currently but will be important for MASS in deciding where they can and can't go. This chimes with the ASV DfT T-TRIG report and RoboSys need for areas of restriction to be made available in machine readable formats.

<u>L3 Harris</u> –
They operate mainly at Degree 3 but can do 4, when in deep water, away from shore and usually when conducting survey activity.
Their general concern is that all data should be machine readable as that is crucial for MASS, human written language is a big issue.
They think it may be useful in the future to have polygons in the ENCs that show what degree of MASS is allowed, so for example in a port Degree 4 may not be allowed, this should be available as interrogable data so the MASS knows whether it can enter a region or not or whether someone needs to take over and operate remotely. This is analogous to the pilot pick up points, where vessels sail to the pilot pick up point and then a pilot comes on board and takes over.
They also feel there will need to be protocols in place to allow MASS to communicate with the shore. This is similar to that mentioned by RoboSys, how would a MASS know who to contact depending on the reporting region it is in. This is shown diagrammatically in Radio Signal, but it isn't shown on charts, will it be covered in S-123?
Speed limits and constraints or rules of the road need to be captured geospatially with appropriate attribution to allow the MASS to interrogate the feature whilst entering it or whilst looking ahead in order to avoid, or behave appropriately, this has been mentioned several times by a number of operators. Generally, they feel a lot more polygons are required. Channels are a good example, they are marked on charts with red and green buoys, but how does a MASS recognise that as a channel, it should be captured as a polygon, again mentioned in the T-TRIG report.
They mentioned a library of real-world images for use by computer vision systems to use for approximation and comparison, which is also outlined in the T-TRIG report. Digital Twins were also discussed as being useful and they described a need for something similar to Google Street View for ships. Particularly when entering a new port.
Certainty of position came up again, with buoys being mentioned as the main example.

They also mentioned the need to understand regular patterns of timings, such as ferry routes, could these routes be captured as corridors with the ferry timetable being made available as attributes.

Kongsberg-

They described the Yara Birkeland (it uses Kongsberg's systems) as a sophisticated level 3 MASS in that it has sophisticated auto pilot features, but it isn't quite capable of Degree level 4. Some of their main issues centred on a need for more topography data or visually conspicuous data for alternate positioning systems.

They mentioned that light sectors can also be an issue for their systems, and they need to know if a light feature will be blocked by land mass that is in front of the light, so they need to understand line of sight from the light feature or any significant navigation mark for that matter. They talked about the resolution and certainty of bathymetry data being a very important aspect. The certainty of data allows them to model risk and vessel behaviour accordingly (e.g., less certainty = high risk profile = behaviour change).

They also would like to understand the drift on buoys, so knowing the length of chain and tidal range would be useful for them.

Ocean Infinity-

We visited their new purpose-built building in Southampton, which is an extremely impressive set up. They are building a fleet of vessels ranging from just under 24m, up to 37m and 5 larger 78m vessels. The smaller vessels will operate remotely at Degree 3, though are capable of operating at Degree 4 of autonomy. The larger vessels will operate at Degree 1 initially with minimal crew, however in time, as regulations allow, they will also be able to operate at Degree 3 and 4. Their Remote Control Centre (RCC) is incredibly impressive. It is a purpose-built room, with lighting, temperature and sound control strictly monitored and controlled. There's 20 state of the art booths with a captains' chair, multiple control surface and screens that can be used to remotely operate vessels anywhere around the world via Sat Comms or 4G.

Dan Hook, their CTO contributed to the T-TRIG report extensively and didn't have much more to add over and above the comprehensive issues and ideas identified in the report. However, in the discussions, real time or actual tide height is becoming increasingly important to them in their business as they are being asked to survey shallow waters and knowing the actual height of water at a given time and location is becoming a key factor for them.

Sonardyne-

Met at their Head Office and Production Facility in Blackbushe. Initially there seemed very little for both organisations to collaborate on or little they could contribute to the IHO MASS requirements work due to their main business being centred on Inertia Navigation System equipment. However, as conversations progressed, we talked about how the use of a high-resolution gridded surface of the seabed (S102) could be used with the INS as a very good back up to GPS. They would need meta data of the S102 (e.g., you can have very high-resolution data that is subject to continuous change like to Humber) so certainty of the data (which has been mentioned several times in previous discussions with other MASS operators) would be crucial before any reliance of the data could be ascertained.

National Oceanographic Centre-

They mainly use AUVs and two smaller USV (sub 2m). They use these somewhere between Degree 3 and 4, in that much of the time the vessels (particularly Wave Gliders) are operating

autonomously, but they are continually monitored and receive instructions remotely. Despite their limited use of USVs they had some interesting requirements for data.
They mainly need the data in their Command and Control (C2) systems and not on board the vessel itself. That said, there were some common themes that came out in discussion that came out from the larger operators. For example, they want to be able to extract features relevant to them such as Traffic Separation Schemes and any exclusion or restriction zones, they talked about a need for more polygons with attribution that can be extracted from an ENC.
They talked about wrecks features being extremely important, today wrecks may be generalised on a chart due to scale, this will probably be the case in S101 going forward. An example of this was offered as wrecks within recognised fishing areas. The implication being that the existence of snagged or discarded nets which may represent a hazard to underwater 'flight' by ROVs. They wanted all of the wrecks data and information about scatter of different parts of the wreck, this is very important for their AUV work. A discussion then ensued around scaleless data for MASS, at the end of the day, scale is a human issue not a machine issue?
Again, they talked about certainty of data, the example being areas that may not have been surveyed recently. CATZOC would probably help here and there is undoubtedly an education piece for NOC as they are not ENC users. But certainty of data is becoming a regular theme so people can modify their risk appetite or mission parameters based on the certainty of data.
Shipping lanes being made available was also mentioned by them, which was also mentioned by BlkSail.
They also talked about the need for more granular information on offshore Infrastructures, for example is the feature still in use, is it being decommissioned, is it no longer in use, how high off the seabed is it etc. The same requirement exists for Wind Farms.
They also mentioned 3D models of Ports and the Seabed becoming increasingly more important, in fact he used the phrase "these are becoming critically important for Remote Control Centres", and we saw 3D digital twins being used in the Ocean Infinity set up, should we move to an official IHO standard for Digital Twins?

WP4: Report what navigational data each member states' regulators (e.g., MCA in the UK) are specifying should be used for MASS navigation in either trials or operations of MASS.

The Maritime and Coastguard Agency is the UK regulator. To date they have no regulations that cover MASS navigation requirements.

The MCA is working on a new Work Boat Code, which will have an annex that will cover regulations for Remotely Operated Unmanned Vessels (ROUVs) which is being finalised before going for consultation this spring.

With regards to the work on guidance for vessels utilising innovative technologies the MCA are primarily focused on informing vessel owners/applicants requesting certification to the UK on the process from start to finish including any additional evidence required outside of the conventional survey and inspection process. This is being handled on a case-by-case project basis. In the assessment of MASS or USVs at the moment, the MCA are generally looking for them to have the same or equivalent navigation equipment as current ships or equivalent size. In general, this means using approved marine equipment such as radars or AIS which share the same information as could be read on board. For chart data, this would involve using official sources of chart data, but this generally needs to be processed to turn it into a format that is readable by the system.

One MCA colleague stated that “there’s a chasm between the MASS operations and any national/international regulations”. Whilst this is true, the UK under the banner of Maritime UK, has established the Maritime Autonomous Ships Regulatory Working Group (MASRWG) which has produced the Maritime Autonomous Ship Systems UK Industry Conduct Principles and Code of Practice (https://www.maritimeuk.org/priorities/innovation/maritime-uk-autonomous-systems-regulatory-working-group/mass-uk-industry-conduct-principles-and-code-practice-2021-v5/). Whilst it must be stated that this document has no legal standing, in the absence of regulations, it is used by the industry and is seen as best practice. Version 5 was published in November 2021 and for the first time, it states that for planning, execution and monitoring of MASS operations, official and up to date navigation products, services or data (i.e., issued by or on the authority of a government or authorised Hydrographic Office) should be used for the intended voyage or area of operation.

WP5: To what degree are member states Hydrographic Offices involved in MASS trials or operations and what data are they currently providing.

The UKHO have been fairly proactive when it comes to working with the MASS industry to identify the requirements for MASS navigation. We have created a MASS navigation strategy, which covers items such as: -

- Supply of free data to MASS operators and builders
- Partnerships in Defence projects particularly the UK’s Defence Science & Technology Laboratory
- Conduct Thought Leadership projects– including academic projects and PhDs
- Influence Regulation
- Invest in S100 standards and capability

The supply of free data to the MASS operators in the UK has been a fruitful exercise in engaging the industry and having conversations about some of the limitations in the current navigation products and standards. Indeed, much of the information and issues outlined in WP3 above has come from this strategy and we have worked with L3 Harris, Thales, RoboSys, BlkSail, Ocean Infinity, Polaris, Atlas Electronik and the Mayflower Autonomous Ship project to name a few. In most instances we have provided S57, Tidal information via an API to allow system to system interrogation, and high-resolution gridded bathymetry.

One of the challenges we have had with the industry, which has been mentioned above, is that little thought has gone into the MASS navigation data requirements. There’s been significant development in sense and avoid technologies and collision regulations algorithms, but in most cases, the industry is trying to make do with S57 and extracting textual information from publications, despite the challenges with these products. The industry, to some degree, is not aware that something new may be required and that S100 is on the horizon. Indeed, most have never heard of S100. As an example of industry making do, we have seen examples of an organisation reverse engineering S57 date to make a 3D elevation model of the seabed. This approach is flawed as the S57 data had 10m contour intervals and was therefore a filtered view of the seabed, when we showed them the seabed in a higher resolution gridded format (similar to S102), they stated that it was exactly what they needed, but didn’t know the data was available. In this example we have technologists bringing new technology to the maritime industry without having previous maritime experience.

The UKHO has also sponsored a number of academic PhD projects with the University of Swansea. We have 2 specific PhDs relating to MASS, both looking at Position, Navigation and Timing and operation of MASS in GNSS denied environments. Clearly MASS will have a strong reliance on GNSS, however, it is easily spoofed or denied and there won't be humans on board Degree 3 or 4 vessels to use alternate methods (such as using a sextant) to determine position. The first PhD has a use case of deep ocean where there are no physical features to triangulate your position from. In this instance the PhD will look at automating celestial navigation to allow the MASS to determine its position. Not trivial in all sea states, poor weather, and a rolling and moving platform. The second PhD has a use case where the vessel is closer to the shore, the intent is to use computer vision techniques to identify visually conspicuous shore features such as buildings or even the topography of the land to then triangulate its position. Both of these PhDs are using machine learning and artificial intelligence and machine-readable data. Whilst the original intent of the PhDs had a MASS use case, the technology could also be employed in manned shipping where the GNSS denial threat is present.

The UKHO have also been exploring how Digital Twins of the marine environment, specifically close to shore and the port and harbour environment, could be used for MASS. The initial use case centres on synthetical trails of MASS for proving the technology prior to operators getting out on water. That said, the Digital Twin as a virtual 3D model of the real world could potentially be used a s a 3D model for MASS to use as a navigation tool, a 3D chart of the future. The PhD mentioned above that is using computer vision techniques to identify shore-based features, could use a georeferenced Digital Twin of the marine environment to compare what it sees on the shore and what it can see in the twin and use that as a method to position itself accurately. Digital Twins of cities have been used in autonomous car developments; it is only natural that this capability would lend itself to MASS in the future. The UKHO has been involved in Digital Twin concepts of the Plymouth Smart Sound and is also producing a Digital Twin of a UK port for future MASS related projects. Some of the challenges with the production of Digital Twins relate to no official standardisation of Digital Twins, joining multi resolution bathymetry together, gaps in survey or very old survey data and joining land and seabed data due to vertical datum shifts.

WP6: Report on what trailing has been done with new navigation standards (e.g., S100) for MASS, or what research into machine readable data has been carried out in each member state's region.

Another project that the UKHO is excited to be working on is how the use of S100 could be used to sail a MASS safely into a port. To that end, the UKHO has commissioned a project with Promare who will use the Mayflower Autonomous Ship to simulate a large Frigate and use UKHO's S101, S102, S104 and S111 to sail into Devonport in Plymouth. This will possibly be the world's first MASS to use S100 and the intent is to both demonstrate the utility of S100 for MASS, and also identify any issues with the data and standard for future development. The integration of the S100 into the Mayflower's AI Captain is currently underway, and the trials will commence on the water in late March. A full report of the challenges of the data standard will be produced for the UKHO, which will be shared with the MASS Nav PT and HSSC. Early feedback from the Mayflower team is that they like S100, far better than S57!