WHERE DOES THE PILOT GO WHEN THE AUTONOMOUS SHIP HAS NO BRIDGE? MASS ROUTING SERVICE AND SMART LOCAL INFORMATION CENTRES

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SUMMARY

The need for pilots with local knowledge of the danger along the coast has been an essential part of safe navigation for centuries. The International Association of Maritime Pilots state on their webpage that "There is no substitute for the presence of a qualified pilot on the bridge." At the same time the International Maritime Organization IMO aims to integrate Maritime Autonomous Surface Ships (MASS) in its regulatory framework, some of which might sail unmanned with no provisions for a bridge onboard. This paper points to this problem and discusses some possible solutions and concludes with suggesting a concepts for a MASS Routing Service based on an automatic Local Information Centre currently researched in the Norwegian project IMAT (Integrated Maritime Autonomous Transport Systems).

1. INTRODUCTION

The need for pilots with local knowledge of the danger along the coast has been an essential part of safe navigation for centuries. In a Scandinavian context the itinerary of the Danish King Valdemar Sejr draws in *Kung Valdemars jordebok* up a 13th century voyage along the Swedish east coast to Finland and Estonia by naming a long list of pilot exchange points and the sailing distance between them [1].

The importance of employing qualified pilots in approaches to ports and other areas where specialized local knowledge is required was formally recognized by IMO in 1968, when adopting resolution A.159 saying it "recommends governments that they should organize pilotage services in those areas where such services would contribute to the safety of navigation in a more effective way" [2]. The International Maritime Pilots Association states under "Beliefs" that "There is no substitute for the presence of a qualified pilot on the bridge" [3].

At the same time IMO aims to integrate "new and advancing technologies" in its regulatory framework and ensure that the regulatory framework for Maritime Autonomous Surface Ships (MASS) keeps pace with the technological development that is rapidly evolving. IMO has tentatively identified four degrees of autonomy, see Table 1.

Table 1. IMO's four degrees of autonomy identified for the Scoping Exercise and approved by MSC 100 in 2018 [4].

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.

From Table 1 we can see that provisions are made for ships without crews onboard and given concept drawings of envisioned future MASS (e.g., Rolls Royce's rendering in Figure 1) with no accommodation for onboard crew or any navigation bridge, one cannot help wondering: where does the pilot stay when stepping onboard? This paper will discuss some envisioned problems regarding pilotage and MASS.

Figure 1. A 3D rendering of an envisioned Maritime Autonomous Surface Ship (MASS) by Rolls Royce used as illustration on IMO's webpage about the subject [4].

2. STATE OF THE ART: SHIPPING TODAY

Shipping is an important part of the worlds infrastructure and carries approximately 90 per cent of all goods transported worldwide. This paper will focus on the safety of navigation as we approach an envisioned transition to autonomous, unmanned merchant ships, and particularly the pilotage part. I will first briefly sketch up stat of the art: what a typical conventional navigation process might look like. In the next section I will discuss how this could be translated into a process for MASS navigation.

A typical bridge team on a conventional mid-size ship consists of a captain and 3-4 highly skilled deck officers responsible for the navigation. In the engine room are equally important officers and crew, but they will be out of the scope of this paper. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) states that "The intended voyage shall be planned in advance taking into consideration all pertinent information and any course laid down shall be checked before the voyage commences" [5]. In praxis it is typically the 2nd officer onboard that is responsible for making the voyage plan before departure. IMO's resolution A.893(21) adopted in 1999 offers guidelines for voyage planning, based on the four explicit stages: appraisal, planning, execution, and monitoring. These stages include the gathering all information relevant to the contemplated voyage or passage; detailed planning of the whole voyage or passage from berth to berth, including those areas necessitating the presence of a pilot; execution of the plan; and the monitoring of the progress of the vessel in the implementation of the plan [6]. I will in the following in some detail describe the requirements of the passage plan to give newcomers a flavour of the work and knowledge involved.

3.1 THE APPRAISAL

The Appraisal stage of the voyage plan, before the ship has departed, includes all information relevant to the contemplated voyage. This includes the ship's condition, stability, equipment, and operational limitations. It also includes its cargo and potential hazard related to it. The ship must carry up-to-date sailing directions, charts, and publications onboard. Also, knowledge of the volume of traffic likely to be encountered throughout the voyage and, if a pilot is to be used, information relating to pilotage and embarkation and disembarkation including the exchange of information between master and pilot. Further, the available port information, including information pertaining to the availability of shore-based emergency response arrangements and equipment. On the basis of the above information, an overall appraisal of the intended voyage or passage should be made. This appraisal should provide a clear indication of all areas of danger; those areas where it will be possible to navigate safely, including any existing routeing or reporting systems and vessel traffic services; and any areas where marine environmental protection considerations apply [6].

3.2 THE PLANNING

Based on the appraisal a detailed voyage or passage plan should be prepared which should cover the entire voyage or passage from berth to berth, including those areas where the services of a pilot will be used. The Voyage plan should include the plotting of the intended route or track of the voyage, the true courses of the route, as well as all areas of danger, existing ships' routeing and reporting systems, vessel traffic services, and any areas where marine environmental protection considerations apply. The plan should include considerations for safe speed, with regard to the proximity of navigational hazards, the manoeuvring characteristics of the vessel and its draught in relation to the available water depth, particularly the necessary speed alterations en route, e.g., where there may be limitations because of night passage, tidal restrictions, or allowance for the increase of draught due to squat and heel effect when turning. Noting especially minimum clearance required under the keel in critical areas with restricted water depth. Course alteration points should be marked, taking into account the vessel's turning circle at the planned speed and any expected effect of tidal streams and currents. The guideline also notes that contingency plans for alternative actions to place the vessel in deep water or proceed to a port of refuge or safe anchorage in the event of any emergency necessitating abandonment of the original plan, should be prepared. The voyage plan should be accepted and signed by the captain before departure of a ship [6].

3.3 THE EXECUTION STAGE

Having finalized the voyage or passage plan, time of departure and estimated time of arrival can be determined with reasonable accuracy. Consideration should be made to the reliability and condition of the vessel's navigational equipment, estimated times of arrival at critical points for tide heights and flow, meteorological conditions, daytime versus night-time passing of danger points, and any effect this may have on position fixing accuracy and traffic conditions, especially at navigational focal points [6].

3.4 THE MONITORING STAGE

The voyage plan with all its details should at all times be available to the officer of the watch. The progress of the vessel in accordance with the voyage and passage plan should be closely and continuously monitored during all times of the voyage [6].

During the preparation of the abovementioned voyage plan the 2nd officer has access to a lot of information through publications (e.g. *sailing directions* and *charts*) as well as on-line sources which publish e.g. *reporting points* and other requirements. However, finding all important information relating to the voyage is difficult and there is often a need for an expert in areas where navigation is complicated, where the traffic volume is high and particular weather and tidal conditions exist. For such areas a maritime pilot is often required.

Pilots have been employed on board ships for centuries to guide vessels out of or into port safely and wherever navigation may be considered hazardous, particularly when a shipmaster is unfamiliar with the area. In addition to local knowledge and expertise, pilots are able to provide effective communication with the shore and with tugs, often in the local language [7]. He or she will be familiar with local ship traffic patterns, tidal currents, and weather phenomena as well as conditions relating to different wind directions and speeds. All of which would be difficult or impossible for a captain unfamiliar with the area to know.

The pilot comes onboard before the ship leaves the port with a detailed plan for the departure. The pilot has a long experience of rudder and engine manoeuvres needed on different types of vessels to leave a berth during different weather and traffic conditions. Before the departure the pilot will brief the captain of his or her planned actions during the formal *Master-Pilot Exchange*. Although the captain still has the final responsibility, it will often be the pilot who conns the ship in the pilotage area, communicating with port, tugs, VTS and other ships on the VHF radio. When entering open waters, the pilot will typically leave the ship, climbing down a rope ladder along the ship side to the waiting pilot boat. Upon arrival at the destination the reverse scenario will unfold.

In the case of MASS, what will this scenario look like?

4. PILOTAGE, MASS, AND AUTONOMOUS, UNMANNED NAVIGATION

Today a lot of research is put into the development of automatically navigating ships. Most research is put into the technical systems and algorithms that will ensure that a MASS can avoid collisions and groundings in an automated way. The soft questions of teamwork between humans and the MASS system have received less attention. The vast repository of local knowledge gathered through generations of seafarers, today often embodied in a local pilot stepping onboard, risk being lost. In this section I will discuss some possible ways of pilotage for MASS.

At 98th session of MSC 2017, IMO recognized that MASS would have impact on many areas including safety, security, interactions with ports, pilotage, responses to incidents and the marine environment. It was also noted the opinion of the majority of the delegations on the need to take into consideration the human element. According to the International Maritime Pilots' Association (IMPA), pilotage is only performed on ships' bridge by a licenced pilot [3]. So far, IMPA has not provided any input paper at MASS discussions at IMO [8] and on IMPA's homepage there is no mentioning of MASS [3]. However, the national Finnish pilot organisation, *Finnpilot*, uses the term *ePilotage* for measures "undertaken to digitalise and develop the different phases of pilotage services in order to make them even safer and more efficient. The key areas of development include the collection, production and processing of information related to pilotage services. The development work will facilitate the provision of entirely new types of services in the future" [9]. At the same token the Finnish project Future Fairway Navigation aims to improve safe navigation for existing vessels and lays foundation for autonomous vessels of the future by experimenting with ePilotage working environment (on shore) and remote pilotage [10].

To ensure safe navigation it will be essential to provide the same type of detailed local information in the autonomous ship system as today is provided for conventional ships though the pilotage system. A Grade 3 or 4 MASS might have no bridge and no one onboard. Instead "the bridge" of a MASS will be the onshore Remote Operation Centre.

4.1 THE REMOTE OPERATIONS CENTRE (ROC)

During the EU project MUNIN (Maritime Unmanned Navigation Trough Intelligence in Networks) 2012 to 2015 this author was responsible for the work package developing what we then called the Shore Control Centre (SSC). Even if we could envision truly autonomous "fire-and-forget, call-me-if-you-run-into-problems" type of ships, we imagined that we for a long time would need to remotely monitor these vessels and be prepared to step in and take remote control if needed. This remote monitoring and control would be done from the ROC. In the MUNIN project a cost benefit analysis was made and the conclusion was that these ROCs would need to be quite big. The concept design was a ROC where six operators monitored some thirty autonomous ships, see Figure 2 [11]. The concept also contained the idea that one operator might supervise several, maybe up to 6 ships during simple ocean traffic conditions [12]. The concept also included a navigation planning unit where voyage plans where prepared according to the guideline from IMO.

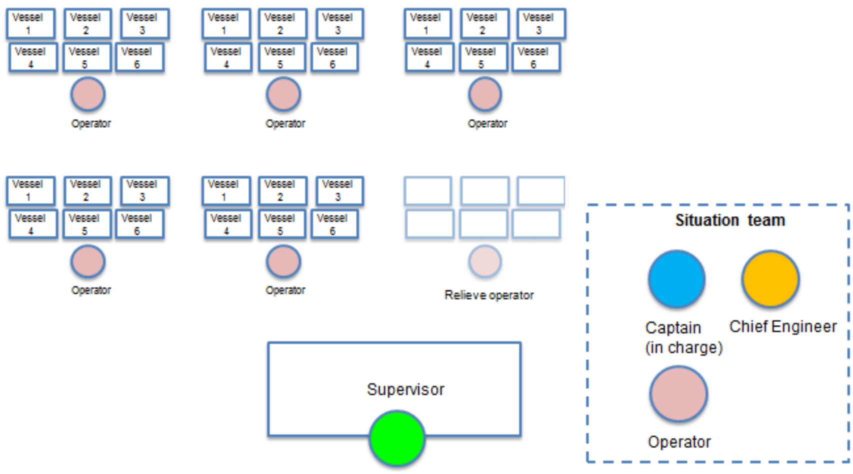

Figure 2. One division operating 30 ships at the operations department at a ROC (from MUNIN deliverable 7.4 "Organization and manning of a SCC" [12].

In the MUNIN project different types of shore control centres were discussed. These could be set up locally, being in charge of ships in that local area, e.g. going in and out of Rotterdam or passing through the English Channel. In this case they would have an area of responsibility very close to what a VTS have today and thereby also a lot of local knowledge. A downside would be many "hand-overs" between local centres where operators need to take over and adapt to the characteristics of new vessels. A type of ROC where the operators instead would be very familiar with their vessels would be a centre type set up by a shipping or manning company supervising a set number of ships wherever they are on the oceans. Manning companies are today often hired by ship owners to man a company's ships and moving the navigational crew into a ROC could be a natural development. The downside here is lack of local knowledge and of course the 24 hours shift work like on the bridge of a conventional ship. In this case the ROC may be in Manilla for a ship entering the Port of Rotterdam. Work conditions could be improved with ROCs stationed around the globe so that ships could be handed over to well rested operators working daylight office hours every 8 hours. The downside here is also the handovers, which requires the operator to be updated on the performance and conditions at the location of the ship, and the lack of local knowledge.

4.2 VOYAGE PLANNING IN THE ROC

The navigation planner in the ROC could be envisioned to have about the same access to information for the *appraisal stage* as the 2nd officer on the bridge if communication with the ships systems is optimal. IMO's guidelines for voyage planning points to the importance of appraising the ship's condition and fitness for the contemplated voyage. This points to the need of robust systems for evaluating and communicating data on remaining up- or lifetime of all ship systems.

For the *planning stage* the nav planner needs to be more meticulous in clicking out the intended passage. All ships are required to make a berth-to-berth plan of the voyage, but for conventional ships (apart from tankers) a detailed path is often made only to the pilot boarding position, stopping there, or taking shortcut into the berth (Porathe, personal communication). If no pilot is boarding, the nav planner needs to design a detailed path, leg by leg, all the way into the dock. Access to on-line information about reporting, position and content of the report, as well as tidal information etc. will be the same as for a 2nd officer onboard. Maybe with the difference that a full time nav planner in a ROC might become more skilled in navigation planning, and information search due to extended practice compared to a traditional 2^{nd} officer.

Once the voyage has started, information about the *execution* and *monitoring* will automatically be available for the monitoring operator in the ROC. One could imagine a streamlined system where planning and execution is done in the same seamless system giving the operator the same, and compared with a 2nd officer onboard, much extended communication capabilities. For instance, the operator could have a better access to real-time information from meteorological and oceanographic buoys, crowed-sourced radars, and cameras ashore and afloat compared to wath an officer on the bridge would have. However, bandwidth limitations could limit the operators access to information from onboard ship sensors.

Finally we have the detailed local information that cannot be read in a book or caught on-line. The detailed knowledge today embodied in the pilot stepping on to the bridge.

4.3 WHERE DOES THE PILOT GO?

A ship with no accommodation and no bridge will not be able to harbour a pilot. From a risk perspective, not having to climb onto a ship from a small pilot cutter in harsh weather on a wagging rope latter, will be an improvement. But the safety implications of losing that local knowledge could be huge. So, what are the possible solutions.

4.4 REMOTE PILOTAGE

Istikbal [8], suggests that the pilot may take over the conning of the vessel from a remote place. This takeover could be from a state-of-the art remote control room at which the pilot feels as if she/he was onboard the bridge of the ship through the use of VR and 3-D technology. Alternatively, the autonomous vessel operator can hold a pilot license for the intended operation areas, which could be possible with ROCs serving smaller areas. However, less likely to be possible for longer voyages.

The European Maritime Pilots Association (EMPA) and the International Maritime Pilot's Association (IMPA) have defined shore-based pilotage or remote pilotage as `an act of pilotage carried out in a designated area by a pilot licensed for that area from a position other than aboard the vessel concerned, to conduct the safe navigation of that vessel [13].

Remote pilotage is already available in some locations. The Rotterdam pilots sometime in harsh weather use radio, radar and binoculars to pilot ships remotely into sheltered waters. Remote pilotage is allowed by Dutch law for pilotage at sea if the pilot cannot be brought on board due to poor weather conditions, if the quality of communication between the pilot and the crew is good, and if the crew is expected to be skilled enough [14].

There have been some studies on remote pilotage, e.g. a Swedish study from SSPA 2007 [15] but there have been controversy involving the pilot unions. Commonly recurring concerns over remote pilotage are the inadequacies of radar, difficulties with language, lack of “feel” for the ship, which includes the on-board pilot's assessment of the quality of the vessel's crew, and the lack of ship motion data [13]. But in the cases referred to here from the first decade of the 2nd millennium, the question was if conventional, manned ship could be remotely piloted. The question now is another: can autonomous, unmanned ships be remotely piloted?

As we have heard, one possibility is to set up local remote monitoring pilotage centres, which in restricted waters take control of a MASS and either use manual remote control or monitors the automation in bringing the ship to port. In either case the pilot will conduct the same task by virtually stepping onboard different ships with different manoeuvring characteristics.

Another possibility is that the Vessel Traffic Service take on the task as source of local information, which to a large extent is inherent in their normal work. However, VTS operators spoken to, and maritime authorities, have been very clear that they VTS has a supervisory role overlooking the traffic of many ships in an area, while a remote control operator or pilot is only supervising the conduct of one single ship at a time. It is a huge difference of perspective.

At the same time there is a hypothesis that much local information can be digitized, in the same way as sailing directions and charts today are. The question is wheatear or not the pilot service as a whole can be automated?

4.5 THE IMAT PROJECT

The Norwegian project IMAT (Integrated Maritime Autonomous Transport Systems) [16], funded by the Norwegian Research Council, started in 2018. The main objective of IMAT is to define, develop, adapt, and test land-based sensor infrastructure used as a support to autonomous vessel navigation and operation. As part of the project a concept for a Local Information Centre (LIC) has been developed. The LIC is a digital repository for information regarding physical infrastructure in the port of Trondheim. This could be such details as the position and capacity of bollards, water and electricity points on the quays, availability of live cameras, live wind shear maps for different berths, timetables for regattas with the local sailing club, timetables and sailing routes (including delays) of ferries and ships trafficking the fjord, tracking of non-SOLAS vessels, leisure crafts and kayaks in the port and fjord area. The project will place test radars/cameras along the fjord and fusing data into a seamless radar map that can be distributed online. Remote-controlled cameras will accessible online. All this live information would be available for the remote control operator.

Future research could involve developing a *Smart Routing Service* from the LIC. The service would be designed to ease the workload of the nav planner in a distant ROC. Instead of collecting and appraising needed local information to make a detailed plan for the arrival to port, the planner would just right-click the Pilot Boarding Position symbol in the electronic chart and select "request MASS routing service" (see Figure 3 for a suggested design).

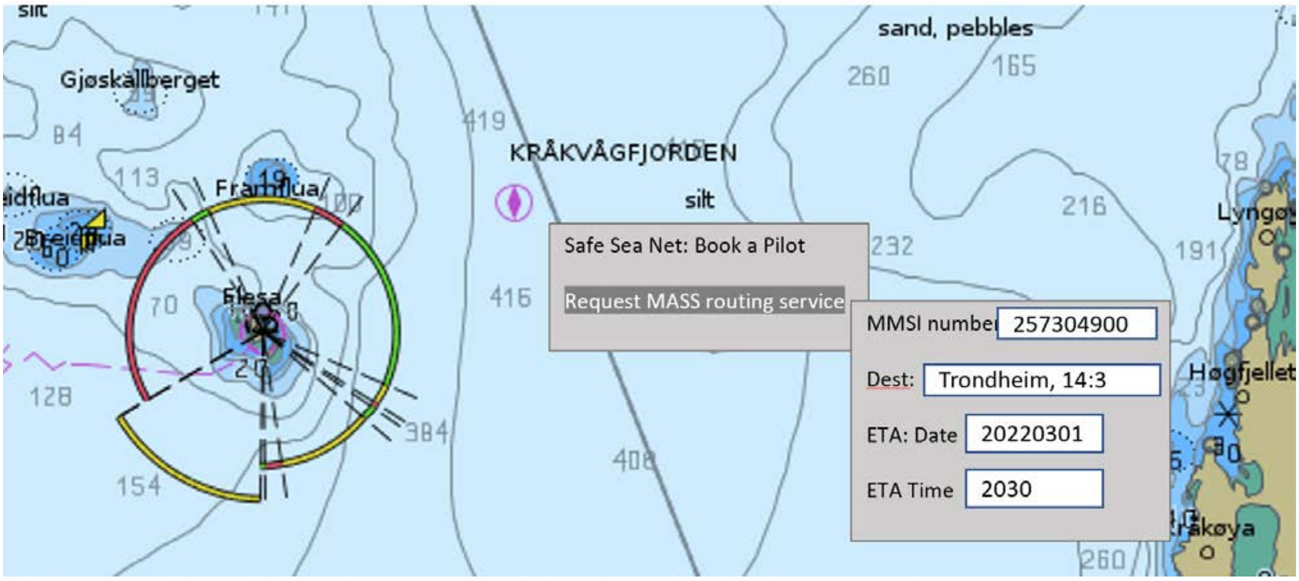

Figure 3. In electronic charts, the symbol Pilot Boarding Point depicts the approximate pilot boarding position. The symbol could also be used as an entry portal to the pilotage booking system, and to book a MASS local routing service from the Smart Local Information Centre.

When requesting a MASS route, the nav planner in the ROC would have to give an estimated time of arrival, a MMSI number pointing to a file with the vessel's ship particulars such as speed envelop, draught, turn radius, etc. These data would then be used to automatically generate a suggested voyage plan for the area covered by the service. It would then be up to the "captain", the operator in the ROC to accept or reject the plan. Having booked the route, the system would keep track of deviations from the estimated time of arrival.

4.6 MASS ROUTING SERVICE

Could such an automated, digital service replace the pilot coming onboard? That is the big question. Researching such a MASS Routing Service could include:

- Route suggestions. In many countries coastal authorities are publishing pilot routes, or recommended routes. In Norway the Norwegian Coastal Administration is presently rolling out "reference routes" [17]. These routes are based on traditional fairways depicted in the charts and in traffic density maps, showing where ships in real life travel and information from pilots, taking into consideration environmental interest as well as a lot of other interests. Many of these reference routes have two-way lanes and are to some extent mimicking a Traffic Separation Scheme.

- Moving Havens. Apart from a geographic path along the fairway, the MASS also needs to be coordinated in the time domain. This can be done simply by showing a moving rectangle in the electronic chart in which the autopilot and the speed-pilot will keep the ship. The width of the rectangle will depict the requested Cross Track Distance (XTD) and the length the requested time precision [18]. The MASS Routing Service will include a Moving Haven based on all available information from the LIC, including currents and tidal information, timetable of ferries and other ship traffic, including known non-SOLAS crafts, diving operations, regattas, etc. The planned route is live and updated with input from traffic delays and other changes.

- Availability of charging points, shipyards, and repair facilities. The operator should easily be able to plan and order charging and repairs along the way.

- Automatic mooring buoys along the route or at an anchorage that can be used to wait out unfavourable currents and winds based on a plan of just-in-time arrival and minimum energy consumption.

- Back-up monitoring. If the ROC should lose contact with the MASS for some time through a communication glitch, the IMAT shore-based infrastructure will be available as a back-up.

The sketched MASS Routing Service based on a Smart Local Information Centre, could potentially make up for problems of bringing physical pilots onboard an unmanned MASS. Future research will show to what extent.

5. CONCLUSIONS

In this concept paper I have presented foreseen problems with Maritime Autonomous Surface Ships that will not be able to accommodate maritime pilots onboard. I have compared the navigation planning routine onboard a modern conventional ship today with what could be envisioned for a future MASS system. This comparison is based on my experience as an autonomous ship researcher for almost 10 years. The comparison ends with a sketch for needed future research on some concepts relating to a MASS Routing Service, which potentially to some extent could mitigate the safety losses occurring by being able to accommodate pilots physically on unmanned MASSs.

6. ACKNOWLEDGEMENTS

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