MARS
A part of NextGen Robotics

WP 1 Papertrail

A framework for understanding the barriers when sailing autonomously

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Introduction to MARS Report

By Project Manager Charlotte K. Flugt (ckf@simac.dk)

This report has been written as a work package delivery under the Danish MARS project (Maritime Autonomous Reliable Systems), and the goal was to look at barriers in autonomous shipping. The report is based on a study of relevant literature, and it was produced from October 2022 to August 2023. The authors of this report are lecturers and associate professors from SIMAC – Svendborg Maritime Academy. Marstal Navigationsskole and University of Southern Denmark.

MARS is an EU funded business development project focusing on the establishment of a test and knowledge center for maritime autonomy in the archipelago of South Funen, Denmark. The test center will be open to entrepreneurs, SMEs, large companies, education and academia from all over the world.

In this report we refer to Danish regulations and Danish implementation of international law, which means that there might be discrepancies between the English original wording and our references.

If you have questions or comments, please contact Project Manager Charlotte Kirkegaard Flugt (ckf@simac.dk)

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Framework Description for Report

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1 Introduction

In 2017, DTU, in collaboration with the Danish Maritime Authority, prepared the report "En foranalyse om autonome skibe" (*A Preliminary Analysis on Autonomous Ships).* The report recommends further analysis of a range of tonnage types, including smaller island ferries and barges used for short sea shipping (1). The argument regarding island ferries is cost reduction, while barges for short sea shipping are seen as an area with great development potential where there's an opportunity to alleviate road congestion. In August 2022, GreenHopper was deployed on the route between Aalborg and Nørresundby. GreenHopper is an electric-powered fjord bus with the potential to be operated without a crew on board. The development has taken place through the partnership Shipping Lab, aiming to create Denmark's first autonomous environmentally friendly ship. The ship has been deployed on the route and sails with a navigator on board; this is a test period to be concluded with a demonstration and test of the ship's autonomous capabilities (2) . GreenHopper is thus the result of the only Danish analysis conducted so far, and it is a ship designed only for autonomous operation.

Internationally, the IMO has worked to ensure a regulatory framework for autonomous ship operation. At a meeting in the Maritime Safety Committee (MSC) 98, a review of the regulatory basis for autonomous ship operation, hereafter referred to as MASS (Maritime Autonomous Surface Ships), was initiated. The aim has been to identify gaps in current regulation, as well as the need for adaptation or additions to the existing regulation. The conclusion of the first review of existing regulation has been that due to the prescriptive formulation, the existing regulation is not suited for direct application for MASS. It is therefore necessary to reformulate or translate the existing prescriptive regulation into goal-based regulation. At MSC 101, the assembly adopted MSC.1/Circ.

1604 Interim Guidelines for MASS trials, which indicates that permission can be granted for tests provided it can be documented that an equivalent level of protection can be ensured in terms of safety and environment as the existing rules, i.e., regulation for MASS is based on the principle of equivalence.

Theoretical studies have been conducted to uncover potentials and possibilities in the use of autonomous ships. The EU-funded study MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) (3) pointed to the advantages of increasing the level of autonomy for selected operations. The study finds that increased autonomy is not just about completely removing the crew, but about supporting the functions the crew has and being able to handle trivial operations that free up resources for other tasks.

Purpose and design

The purpose of this report is to uncover potential, opportunities, and barriers associated with an increased level of autonomy in ships. The report establishes a common framework for and understanding of the barriers to sailing with autonomous ships.

The purpose of this part of the project is to examine autonomous ship operation from a risk perspective that includes regulation, technical maintenance, cyber security, societal readiness, safety, and environment. The analysis is based on three cases. Two existing island ferries, each with their level of sensor technology and data collection, and a non-existing scenario (4), based on what Mogens Blanke et al (2017) describe as a barge used for short sea shipping. Each case is analyzed from a legal, risk, and cyber security perspective, where the risk assessment will focus on safety, maintenance, and environment. It also includes a sub-report focusing on Societal readiness. Five chapters are prepared.

Chapter 1 Legal Barriers

Chapter 2 Safety and Risk Assessment in relation to Autonomous Vessels

Chapter 3 Cyber and Information Security

Chapter 4 Society's readiness for Autonomous Shipping

Chapter 5 Technical maintenance of Equipment on Autonomous Ships

2. Cases

The three cases the report is based on are respectively M/F Højestene, E/F Ellen, and an unmanned barge. The barge is described as a future scenario. The three subsections below describe each of the three cases.

2.1 M/F Højestene

M/F Højestene was built at Torshavnar Skipasmidja, Faroe Islands for ferry operations between Svendborg, Skarø, and Drejø. The ferry was launched and put into operation in April 1997.

M/F Højestene has a length of 31 m and a width of 10 m. The ship is propelled by 2 Volvo Penta diesel engines with a total of 749kW, and it has a top speed of 11.6 knots.

It is described as a Single ended, drive-through Ro-Ro Passenger ferry.

The ship has a crew determination of 2, a shipmaster and a mate.

Name	m/f Hoejestene
IMO	9169794
Built / Yard	1997 / Tórshavnar Skipasmiðja
LOA	31 m
B	10 m
Draught	2.10 m
Service speed	11.6 knots
Engines	2 x 750 kW Volvo Penta

Figure 1 Data on Højestene (source: VesOps)

Current autonomy level

M/F Højestene is equipped with an Autopilot, an ECDIS, and an ARPA-radar. Course instructions to the autopilot are provided by the crew. The level is described as manual steering since all decisions are made by the operator (navigator) without decision-support systems. However, an autopilot as an independent system is considered supervised autonomy as the system performs self-calculating actions to maintain the desired course. This, however, is only at the system level.

Sensor Technology:

Radar: JRC JMA-5312 which communicates via the NMEA0183 protocol and a Furuno MARINE RADAR Model 1831 MARK-2 which communicates via IEC61162-1 (NMEA0183) protocol used by the lookout.

GPS: JRC JLR-4341 DGPS Sensor which communicates via the NMEA0183 protocol is also used as a compass.

AIS: Koden KAT-100 Class A AIS TRANSCEIVER which communicates via IEC61162-1 (NMEA0183) protocol.

Echo Sounder: Furuno FISH FINDER Model FCV-628/FCV-588 with color display which communicates via the NMEA0183 protocol.

Propulsion machinery: 2 pcs. Volvo TAMD 163A-A 374.5 kW (total 749 kW so only a "motor operator certificate" is needed)

Auxiliary machinery: 1 pc. SB Volvo TAMD 71A 125 kVA and 1 pc. BB Volvo TMD 102A 125 kVA, which are started from the bridge during maneuver and power the bow thruster.

From the company VesOps by Søren Vinther Hansen, who has created an app for Højestene, information in Figure 2 has been received. Besides VesOps data loggers, there is some central access to data from the ship.:

Drejø – Skarø (Højestene)

	Loggers installed
RPM	ME tachometers
Speed, course, position	ECDIS
Fuel consumption	Flow meter (installed)
Depth	Echo sounder
Wind	Anemometer

Figure 1 – Datalogger Kilde: VesOps

Figure 3 – Højestenes rute Kilde: Svendborg-havn.dk

2.2 E/F Ellen

E/F Ellen is the result of the Electric-ferry project, E-ferry, a four-year EU funded innovation project (5) with the aim to design, build, and test a 100% electric-powered, medium-sized ferry for passengers and vehicles, trucks, and other cargo. The goal was to promote energy-efficient, CO2 neutral, and pollution-free waterborne transportation on island routes and in coastal waters in and outside Europe through a demonstration project. The electric ferry project builds on the preliminary study supported by the South Denmark Growth Forum, Green Ferry Vision (6).

The electric ferry, 'Ellen', has a range that is 7 times longer than any other fully electric car ferry. On the route between Søby and Fynshav, the ferry sails up to 22 nautical miles (about 40 kilometers) round-trip to the charging station in Søby. Ellen can actually sail much further - thus the operator, Ærøfærgerne, has demonstrated two round trips without a charge. However, as the operator wants to maintain a high frequency, the batteries are not completely drained; instead, Ellen 'trickle charges' the batteries every time she is in Søby Harbor during the day. This means that Ellen can sail up to 7 round trips daily.

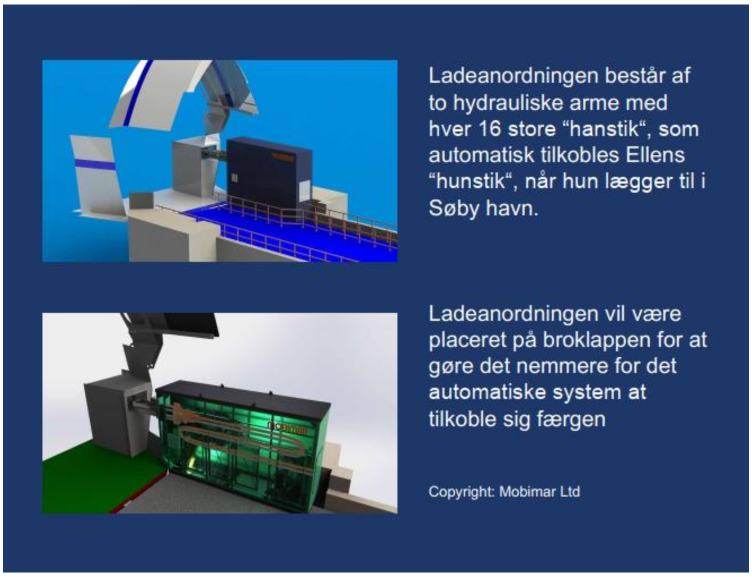


Figure 2 - Ladeanordning Kilde: www.el-færgeprojekt.dk

The crew on Ellen consists of a skipper, a mate, and a safety worker (sailor/catering) on a daily basis. If the number of passengers exceeds 147, there must be an additional safety worker on board. Besides, Ellen has a chief engineer and a sailor who flex between several different ferries, although they do not participate in the daily operation.

Sensor Technology

Ellen is equipped with a Valmet DNA Integrated automation system that receives data from the ship's bridge, a Furuno Voyager Integrated Navigational System. Data from all bridge instruments are collected and forwarded via the NMEA0183 protocol. The bridge system also has the capability to communicate on the more modern NMEA2000 protocol. The bridge is also equipped with an Airmar 150-WX ultrasonic weather station, which likewise communicates via NMEA0183

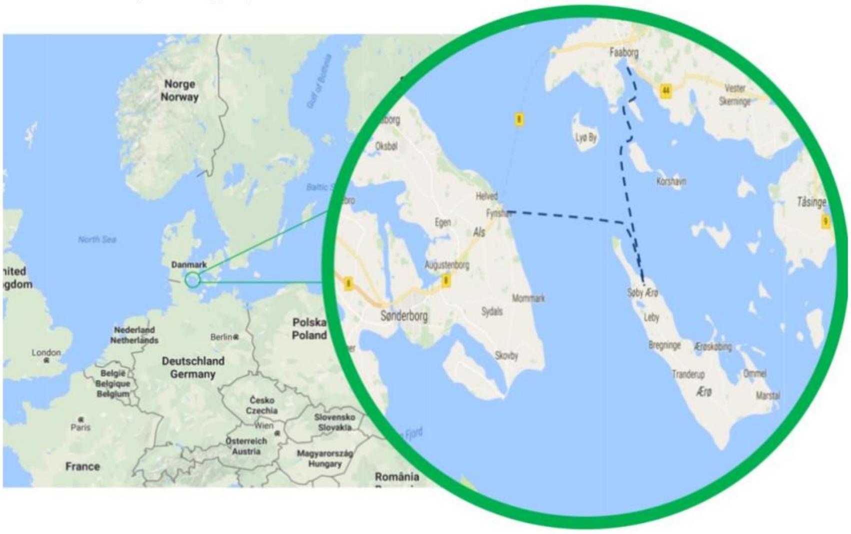


Figure 3 - mulige ruter Kilde: Jens Kristensen Aps

or NMEA2000. The weather station is equipped with independent compass and acceleration sensors for the calculation of pitching and rolling.

The ship is equipped with optical measuring equipment for draft fore and aft that can be used among other things for calculating the ship's trim, draft, and displacement. Data from here can be accessed via the Valmet DNA system. The Valmet DNA system also has access to data from the ship's power management system where a wide range of data about the ship's electrical status can be accessed.

	Technical characteristics
Type	Single ended, drive-through Ro-Ro passenger ferry
Class notation	1A1, Car Ferry B, R4, ICE C, EO, Battery (Power)
Transport capacity	31 cars or 4 trucks and 8 cars, 147 passengers in winter, 196 passengers in summer
Dimensions	Length 59.4 m, breadth 12.8-13.4 m
Speed (draught of 2.30 m)	13-15.5 knots
Deadweight	235 ton
Gross tonnage	996 ton
Propulsion	2x750kW main motors, 2x250kW thruster motors
Battery capacity	4.3MWh
Charging capability	4MW
Battery weight	56 ton

Figure 4 - Tekniske speficikationer Kilde: Jens Kristensen Aps

Lastly, Ellen is equipped with a stand-alone Cavotech automatic mooring system. For safety reasons, this is not integrated into the Valmet DNA system.

Current Autonomy Level

Despite its high level of digitalization, Ellen is not equipped with automation other than what is normal for ferries. That means she has the standard ARPA, ECDIS, and autopilot systems which are part of the Furuno Voyager bridge system. It is unclear whether it is possible to provide external inputs to this system digitally.

2.3 Barge

The two preceding scenarios are based on already existing platforms. And their contribution to this study will primarily be to see what can be done with existing technology.
At the same time, both first two cases are built on the idea that the crew should not be removed from the ship. This is done based on experiences from previous projects (7), where transporting passengers itself is a barrier when the crew is removed from the ship.
The purpose of the future scenario is to investigate a design of a vessel that does not have a crew on board but is connected to a land-based control center. Since there is already a study underway for

passenger transport (8), we choose in this scenario to focus on other needs.

What the future needs can be is very difficult to predict, but some possible areas could be: Transport of smaller amounts of goods between regions, seabed surveying, water sample collection, servicing of sea marks. Setting up and maintaining underwater infrastructure.

Handling all these diverse tasks could be thought to be solved by having a standard platform, upon which different modules could be mounted as needed.
Such a platform solution would open up a wide range of business cases, but its exact design will not affect the result of the investigations this report aims for.

A likely design could be a smaller version of the self-sailing barge Space-X uses as a landing platform for its rockets. Maybe adapted to a standard 20-foot container.

Figure 5 - Space-X platformen A Shortfall of Gravitas
Kilde: https://www.bairdmaritime.com/

Such a vessel is either capable of sailing independently under normal conditions, but under supervision and responsibility from a control station on land or is directly remote-controlled from a station on land.

It is thus equipped with enough sensors to form a complete picture of its surroundings. And enough communication equipment to transmit this picture to the station on land.

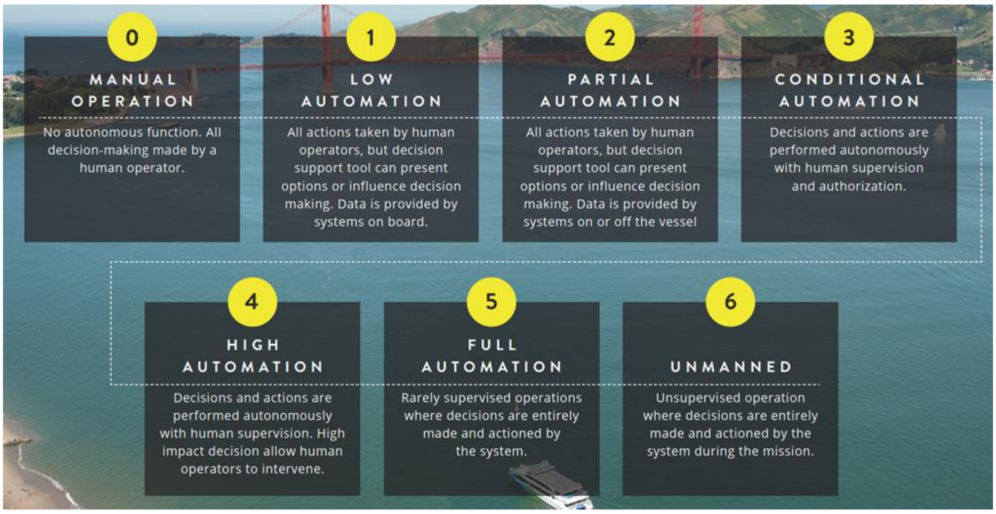
In addition, the vessel must at a minimum have enough autonomy to be able to handle a loss of communication. In the report, this scenario is treated both as a self-sailing and as a remote-controlled ship, which is what IMO categorizes respectively as category 3 and 4. These categories are further described in section 3 on autonomy levels.

3 Autonomy Levels

The concept of autonomy is disputed, which is why it is found necessary to define the term as it is used in this report. Eriksen (2021) concludes that there are three essential characteristics of autonomous systems, (1) the system makes decisions itself, (2) the system is appreciating and projecting, and (3) the system operates independently of an operator. The fully autonomous ship operating without human intervention is considered an end result, where along the way there are a number of steps that each increase the level of autonomy. Here the focus is first on developing systems that are appreciating and projecting, thereby supporting the operator's (navigator's) decisions, at the next level the system itself makes decisions but is monitored by an operator, to finally be able to operate independently of this.

If you zoom in on the individual operation on board, it is seen that these can be assessed individually in relation to the level of autonomy. It is the assumption in this report that in a development towards the fully autonomous ship, there is a need for every operation (and subsystem) to be assessed and developed, so that over time it can be carried out without human intervention and that only when these operations can be performed fully autonomously, they will be systemically interconnected and the fully autonomous ship can be achieved. However, it is important that when the individual system is assessed, thought is given to the relationships with other systems and the value of and the need for interconnecting the systems.

There are a number of tables for indicating levels of autonomy, Blanke et al (2017) takes in this report the basis in Lloyds Registers (LR) definition of autonomy levels and takes the basis in the navigation of a ship, a total complex operation which includes both lookout and speed which are the two sub-operations dealt with in this report. The levels go from AL0 to AL6, where AL0 is denoted as manual control while AL6 is full autonomy. It is assessed that LR's definition of autonomy level is recognized and accepted as a reference framework in the industry. Below is a description based on LR and prepared by Sea Machine (9).



IMO works with four categories here the starting point is that category 1 is what the ships operate on today. The four categories are described in the list below.

(1) Ships with automated processes and decision support: Here the seafarers are on board, and it is they who make decisions, there are systems that operate autonomously, but they are monitored and there is an opportunity for intervention.

(2) Remotely controlled ship with seafarers on board: The ship is controlled from an external control center. There are seafarers on board who will be able to intervene and take over control.

(3) Remotely controlled ship without seafarers on board: The ship is controlled from an external control center. There are no seafarers on board.

(4) Fully autonomous ship: The ship makes decisions itself, is appreciating and projecting, and operates independently of an operator. (10)

IMO's 4 categories form the basis for the work that the maritime safety committee (MSC) has set in motion to investigate the status of MASS and the existing regulation. Here the assumption is that the existing regulation is prepared to regulate shipping at level 1 and that a change in location of control and control of the ship has significance for the regulations. So, it is not a hierarchical division where you move from one level to the next. IMO's description is aimed at 4 categories, each of which may have its own special regulatory requirements going forward as seen, for example, in relation to tank ships and general cargo ships.

This report uses the level division AL0 to AL6 when referring to a single system, as this is the prevailing division used by the industry. Since a system is assessed individually, a ship that as a whole is categorized in IMO as a category 1 ship and where systems operate together as AL0 can well be equipped with a single system that individually can be assessed as an AL4. This is seen for example in relation to the ship's autopilot which, based on a programmed course, itself sends rudder commands to the steering machine to keep the ship on the specified course, only if it cannot maintain the specified parameters will it sound the alarm and the operator will take over.

In relation to the 2 cases Højestene and Ellen, 3 operations for increased autonomy have been selected, each of which is expected to be able to relieve the workload from the duty navigator and at the same time increase safety. These form the basis for auto anti-collision and auto navigation which are the basis for the future scenario.
The three selected areas are; 1. auto-lookout, 2. auto-speed, and 3. auto-docking and these are described in the following subsections.

3.1 Auto-Lookout

An auto-lookout system can be seen on a wide range of levels and with different involvement of technology. Basically, the purpose of such a system is to ease the helmsman's task of keeping a lookout around the ship while it is in motion. At the higher levels of autonomy, the system is also an integrated part of an autonomous vessel, where its task is to provide the system with the necessary situational awareness.
In relation to different levels of autonomy, one can see that there already today exist a number of systems to detect and provide decision support in connection with the lookout. Modern radar systems must be equipped with automatic plotting assistance (ARPA) that can determine the course and speed of other objects, as well as calculate the closest point of approach and time (CPA, TCPA). Likewise, merchant ships today must have automatic identification (AIS) that enables other ships to see a variety of information about the ship. These systems are appreciating and projecting, however only to an extent that supports the operator in their decision. All island ferries can thus already today be said to be between level AL 1 and 2. However, these systems are only to be considered as support functions for the actual visual lookout that today is performed by a person who is approved to be able to keep a lookout on board a ship. The purpose of an automatic lookout system as

investigated in this report is primarily to be able to lift the visual task that today is handled by the navigator in order to contribute to increased safety on board, and secondly to be able to "keep a lookout" together with the existing systems of today.

Two examples of systems that lift the visual part of the lookout function are; Sea Machines AI-RIS (11) and ORCA AI (12). Both systems are based on a combination of camera technology and artificial intelligence. The cameras are used to create the visual overview, while the artificial intelligence is used to identify and classify the observed in similarity with a trained human lookout. By combining current electronic systems (RADAR, ARPA, AIS) with the visual systems, the situational awareness necessary for autonomy level 3 can be achieved.

At level 4, the system will, in addition to being able to identify all types of objects, also be able to prioritize them in relation to the importance of the ship's safe navigation and come up with recommendations for actions that best avoid identified danger points and ensure the ship's optimal operation.

The highest levels of autonomy (AL 5 and 6) are not relevant for a stand-alone auto lookout system as they require integration with other ship systems such as route planning, maneuvering, and speed. These higher levels will thus only be applicable when looking at a more integrated system.

3.2 Auto-Speed

Automatic control of the ship's speed is not very common at sea today. Most ships today have a completely manual system, where the navigator sets the ship's engines to a certain performance in percent or revolutions per minute. So, the normal today is autonomy level 0.

The purpose of automatic control of the ship's speed is to improve operational economy. The ship's energy consumption is heavily dependent on external influences such as water depth, wind direction and strength, and waves. Studies have shown that significant savings can be achieved with a more dynamic adjustment of the speed, but this requires the integration of several sensors on board the ship (13).

At lower levels of autonomy (AL 1 and 2), an auto-speed system must be able to integrate information about the nature of the water, such as water depths, current, and wind, with a hydrodynamic model of the ship and come up with recommendations to the helmsman regarding the most optimal speed at any given time. Such integration can happen through the ship's own sensors or with the help of external sensors on land. For example, all ships are equipped with a weather station, just as the Danish Geodata Agency and the Danish Meteorological Institute both have the opportunity to provide the necessary external data.

At higher levels of autonomy (AL 3 and 4), the system, in addition to the above, should also be integrated with the ship's maneuvering system so that the speed can be adjusted automatically. This presents a number of new challenges. The ship's speed is thus an important part of the anti-collision effort, just as a course change can be thought to lead to an unintended change in the ship's speed. It will therefore be necessary to have approval from the ship's helmsman (AL 3) or a digital analysis of the consequences (AL 4) before a speed change is implemented.

Just like on the lookout system, there is not much value in the highest levels of autonomy (AL 5 and 6) when we look at a stand-alone system. These levels only come into their own when there is an integration between all the different systems and at the same time an automation of the general navigators function occurs.

3.3 Auto-Docking

Docking the ship has long been one of the most difficult maneuvers the captain must perform. At the same time, it is an area that requires a very high level of detail in information about the ship's position and direction. Therefore, it is also a system that will place great demands on both sensors and integration.

On large merchant ships, a very small part of the total operating time is used with docking. The opposite is true for ferries that have many calls during a day. Therefore, it makes sense to look at automatic systems for docking specifically in connection with smaller island ferries.

The purpose of an auto docking system can be measured on two primary parameters. Firstly, the system can help counteract human errors in connection with docking, thereby increasing safety, reducing repair costs, and improving timeliness. Secondly, the system can help reduce energy consumption and the time spent on docking, thereby saving money on fuel as well as increasing the ferry's timeliness and frequency.

Today, most smaller ships are at autonomy level 0. Some can be said to have an autonomy level 1 in the form of a conning display, such as K-bridge (14), which presents a range of sensor information to the captain (e.g., direction and speed of movement). However, these systems do not have dedicated decision support, and usually cannot present the ship's position relative to the quay.

To achieve full level 1 or 2, it would be necessary to combine a conning display with new sensors, such as Trelleborg's smart docking laser (15), which provides the necessary level of detail regarding the ship's location. Similarly, it would be necessary to develop a decision support system that can calculate the best maneuver to dock.

At higher levels of autonomy (AL 3 and 4), the system should be capable of taking over the actual maneuvering of the ship in docking situations to some extent. Here, one can draw on the many experiences from the offshore sector and the use of dynamic positioning systems (16).

For all levels of autonomy in docking, it will be necessary to consider human involvement. Maneuvering often goes very quickly, with only a few seconds to make the right decision, so communication of easily understandable information to the captain needs to be considered in the system.

3.4 Auto-navigation and Auto-anti-collision

The future scenario is based on an autonomous drone in category 3 according to IMO's MASS taxonomy (systems would then be at AL 5 to 6 level). Meaning a vessel that is exclusively remote-controlled from land. Depending on whether this remote control is done as direct control or monitoring, there will be different requirements for the systems on board.

Figur 6 - eksempel på landstation
Kilde: https://www.massterly.com/

The simplest scenario is direct remote control. Here, the vessel must be able to create the necessary situational awareness around itself and transmit this to the land station. The challenge can thus be equated with the auto lookout system mentioned earlier. To this, a communication system to land and a land station must be attached. The land station can in many ways be said to resemble already existing full mission simulators or ROV stations.

The biggest challenge probably arises in relation to communication between the vessel and land. Here, it will be necessary to look at redundancy, data security, and the vessel's action patterns in case of connection loss.

In the scenario where the vessel is only to be monitored from land, and thus must be able to make a wide range of everyday decisions independently, it will be necessary to have all the aforementioned systems at a high autonomy level, just as it will be necessary to look at more overarching navigation systems that can perform anti-collision and dynamic route planning at level 4 or 5.

Anti-collision at level 4 and 5 will among other things require the ship to be able to comply with the rules of the road at sea, just as it must be able to relate to waterway marking. There are no systems today that have shown this level fully, but several have shown parts of a solution. Examples include the Norwegian Yara Birkeland and the Japanese MEGURI2040 project (18).

4 Method

The data underlying the individual chapters was collected in the period from October 2022 to April 2023.
The first chapter, which deals with the legal aspects, primarily uses regulation, and considerations in connection with the development of new regulation, from the International Maritime Organization (IMO), these have been accessed via IMODOCS (19) and form the background for the analyses in chapters 1 and 2. Danish special law, which has been accessed via retsinformation.dk, is also included in these analyses in order to determine applicable law. Knowledge and data from a number of projects that have been carried out within the area are included in the analyses in chapter 2 including HUMANE (20), MUNIN (21), Via Kaizen (22), SAFEMASS (23), RBAT (24), ECOPRODIGI/EXOPRODIGI (25), Stena Fuel Pilot (26), Shipping Lab (27), and Yara Birkeland (28).

In addition to the written material, two workshops have been held, one with an overarching theme aimed at supporting the initial process (a joint brainstorm) and the other focusing on competencies. The first workshop was held after the framework for the report had been set up. Experts from authorities and business as well as members from the project group participated in the workshop, which was held on January 31, 2023. There were 18 participants in the meeting, which was held as a hybrid, between online participants and physical presence.

Participants were presented with the 3 cases. Subsequently, each system was treated individually auto-speed, auto-lookout, auto-dock, auto-nav, and auto-anti-collision. Participants first individually noted the issues they identified, and then they were categorized in relation to whether it was related to regulation, safety, environment, societal readiness, or maintenance. Subsequently, the identified issues were discussed in plenary, main points were written down by the secretary and all issues that had been brought forward were written down. The purpose of this workshop was to qualify the work in the individual chapters inspired by the work done in the HUMANE project. (29)

On June 10, 2023, a workshop was held at Marstal Navigation School, this time focusing exclusively on competencies. 10 experts from the two educational institutions MARNAV and

SIMAC participated. The purpose of the workshop was to compare the competency requirements arising from increased autonomy with the current educations and uncover new educational needs (30).
Reports from the Center for Cyber Security have been used as primary empiricism for chapter 3 on cyber security. A theme day on Cyber Security with 50 participants from both business and authorities was held on April 18, 2023. (31)

To include the Nordic perspectives and discussions that are valid within both industry and research, the group behind the report participated physically in the seminar *AI i Sjöfartens Tjänst* in Gothenburg (32), as well as the network meeting titled *Menneskets rolle i nye teknologier og driftskonsepter - Will Industry 5.0 herald the revenge of the humans?* in Ålesund (33). Both meetings have helped to qualify the reports through discussion and sparring with others working within the same field.

5 Limitations

The present reports have been prepared under the direction of the MARS project which is part of NextGen Robotic. It is a matter of covering knowledge within "Maritime Autonomous Surface Ships (MASS)", where results from international studies are included and held up against IMO's legal work. Thus, it is not a research project. The chapters are designed and set up to be informative and can qualify the further work in the MARS project by pointing out the areas where there is a need for further investigations.

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Chapter 1
Legal Barriers

By Kresten Petersen, MARNAV (KP@marnav.dk)

1 Introduction

In this chapter we will examine the legal obstacles related to our three use cases. As a basis for this study, we will consider three previously conducted analyses of challenges related to the implementation of autonomous systems in ships.

The first is a report from the Technical University of Denmark (DTU) and the Danish Maritime Authority, titled *En foranalyse om autonome skibe* in English 'A Preliminary Analysis on Autonomous Ships' (DTU, 2017), which, among other things, contributed to the classification of autonomous levels. The second is an analysis by Rambøll and CORE law firm *Analyse af reguleringsmæssige barrierer for anvendelse af autonome skibe* (Danish Maritime Authority, 2017) on regulatory barriers for the use of autonomous ships. Here, all identifiable barriers for autonomy have been reviewed. From this, we have extracted the rules believed to be relevant to our three use cases. The third is the International Maritime Organization's (IMO) "Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships" (IMO, 2021). Here, the IMO's Maritime Safety Committee (MSC) has examined which parts of the existing IMO regulations need adjustments for different levels of autonomy. From this, international rules relevant to our cases have been extracted, with a focus on elements identified as high priority (see Figure 1).

IMO Instruments
SOLAS II-1
SOLAS II-2
SOLAS III
SOLAS IV
SOLAS V
SOLAS VI
SOLAS VII
SOLAS IX
SOLAS XI-1
SOLAS XI-2
COLREG
STCW
STCW-F
LL 1966 + 1988 Protocol
SAR 1979
TONNAGE 1969
IMDG Code
IMSBC Code
FSS Code
IBC Code
IGC Code

Figure 1 List of IMO Regulations with high priority.

In addition to these three sources, a workshop was held with participants from Svendborg Maritime Academy (SIMAC), Marstal Navigation School (MARNAV), University of Southern Denmark (SDU), Bureau Veritas (BV), and the Danish Maritime Authority (DMA). At this workshop, challenges related to the implementation of autonomous systems were brainstormed in general, and legal barriers were discussed on par with a range of other issues. (1)

Since some of the sources for this study are a few years old, a check of current Danish legislation has been made to detect any changes since the sources were investigated. Similarly, the results from the workshop have been checked against current legislation. The three sources are considered to collectively cover the legal framework within which autonomous vessels operate. Therefore, no further exploration regarding national or international legislation that might affect the ability of autonomous units to operate in Danish waters has been undertaken.

The three use cases cover different systems to increase the level of autonomy in existing and upcoming ships. However, the legislation is not structured around individual systems. Therefore, it doesn't make sense to strictly follow the use cases in this chapter. Instead, different groups of legislation have been considered, inspired by the classification from the Danish Maritime Authority's report. In individual chapters, it is highlighted how this may be thought to influence the opportunities and limitations in the use cases.

2 Results from the Workshop held on January 31, 2023

During the workshop, legal barriers for the various use cases were discussed. It quickly became clear that the workshop participants saw a distinct divide between the first two use cases, where onboard systems supported an existing crew, and the last case, where a unit is unmanned and controlled from shore. A similar distinction has been identified in the report of the Danish Maritime Authority and in the work of the IMO.

The results of the workshop can be summarized in the following points:

Acceptance Criteria. What criteria should be set for a system to be approved? The question was particularly whether a performance standard should be developed first, similar to those found in other regulations (2), or whether systems could be approved individually during a test phase.

Workshop participants believed that the approval of individual systems would be the solution for a prolonged phase until the systems mature and there is a body of knowledge about their operation in real situations (3). It was also believed that the current approval system for such tests was too extensive. Participants from the Danish Maritime Authority emphasized the organization's initiatives under the Future Lab department but also sought more knowledge and input on how an approval procedure could be made more agile and how safety risks from experimental arrangements could be covered.

Navigational Rules. The systems will interfere with the International Regulations for Preventing Collisions at Sea 1972 (COLREGs), especially rules 5, 6, and 8 (4). Therefore, it will be necessary for the administration to establish rules for how these systems should be viewed in relation to these rules. There was general agreement that if we're talking about support systems for an existing bridge crew, there aren't significant challenges in a legal sense. Here, the on-duty officer and the ship's master will still bear the responsibility, just as they will have to show the necessary degree of good seamanship that the rules are based on. There was more uncertainty when talking about maritime autonomous surface ships controlled from shore, use case 3 and IMO level 3. The fundamental problem was identified as the question of situational awareness. COLREGs state, among other things, that *'Every vessel that shall at all times maintain a proper lookout ……. by all available means …… so as to make a full appraisal of the situation and of the risk of collision'* (5). Systems on board a remotely operated vessel must thus be able to provide this level of situational awareness. How this is to be documented is still not regulated, but individual risk assessments of various systems and solutions will likely be required before more general requirements for equipment on such a vessel can be formulated.

Responsibility. Who is responsible if the systems overlook something or makes wrong or dangerous decisions? The questions mainly revolved around the independence of the systems. Are they only presenting information to the on-duty officer, who then makes their own decisions? Or do the systems go further and can perform independent actions on the ship's navigation. In the first case, no difference was seen between current systems such as RADAR or ECDIS, while in the second case there was a need to clarify responsibility. The workshop participants believed that, as a starting point, the existing allocation of responsibility between the ship's master, manufacturer, and shipping company would not change. Therefore, responsibilities should be able to be accommodated within existing frameworks.

Education. Since the systems are new, it cannot be expected that existing officers can use them without thorough training. Therefore, the workshop identified a need for educational requirements like those for other modern electronic aids. Examples include RADAR/ARPA, ECDIS, AIS, and GMDSS, all of which today require special courses, either as part of the master mariner education or as further training before they can be used by the ship's crew. Something similar will be necessary in relation to the systems mentioned in the use cases.

3 Regulatory Barriers

In the following sections, we will look at different areas of potential barriers for autonomous units at various levels.
First, we briefly look at jurisdiction in the area, followed by the ship's navigation and the barriers that can be identified in relation to the navigation itself. Then we focus on the crew and the sets of rules that deal with their role, education, and responsibility. Lastly, we focus on the technical aspects of the ship's equipment.

3.1 Jurisdiction and the Concept of a Ship

The concept of a ship has never been unambiguously defined in Danish legislation. There are different definitions in international law (6) and in the Danish 'Merchant shipping act'(7), but they all have in common that they define the concept of a ship from a functional perspective and in relation to the given legislation. However, ships usually have some characteristics: they must be able to float on water, be able to move on water, but do not necessarily have to have its own propulsion, and they must have a certain size.
This loose definition means that autonomous units are presumed to be defined as ships.

According to UNCLOS, there must be a "genuine connection" between the ship and its flag state. (8) This genuine connection, among other things, obliges the flag state to establish rules for ships flying its flag and to ensure that its legislation is complied with on the ship. The UNCLOS also extends this supervision obligation to the education of the ship's crew and sets requirements for the ship's condition while it flies the State's flag. (9)

In Denmark, according to 'the merchant shipping act' only vessels above 5 BT can be registered. (10) The Danish implementation of SOLAS determines that the rules apply to merchant ships above 15 meters in length, but there are also sets of rules without a lower limit. For instance, there is no lower limit with regard to COLREGs, and the 'act on safety at sea' states that all ships, regardless of size, is required to have a master onboard. (11) Only vessels that apply to these limits are subject to inspections and surveys from the Danish authorities.

In addition to its jurisdiction as a flag state, Denmark has jurisdiction as a coastal state and port state. As long as navigation takes place within the territorial limit of 12 nautical miles, or from a Danish port, Denmark has full jurisdiction over the ship in accordance with the UNCLOS convention's article 2 on the sovereignty of coastal states. (12) Therefore, it can be concluded that the use cases this report deals with fall within Danish jurisdiction, whether we're talking about support systems for an existing crew or remotely controlled units. However, in relation to use case 3, there are differences in how many rules a vessel must comply with depending on its size, and this will influence the approval of the individual vessel.

3.2 Ship's Navigation

It is fundamental principle of ship navigation that 'each ship is in the charge of a master…. who possess appropriate qualifications' (a competent master). (13) However, in only a few cases is it directly emphasized in the rules that the navigation of the ship should take place physically from the ship's bridge. (14) A significant challenge, therefore, becomes the question of whether the bridge can be physically located somewhere other than onboard or whether the bridge can be unmanned at times.

In the COLREGs, rule 2, 5, 6, and 8, the basic rules regarding compliance with the rules of the road are established. The focus here is on who is steering the ship and not from where the ship is being steered. At the same time, there's a focus on the ship always being under human control and that there's an opportunity to intervene in unforeseen situations.

Rule 2(2) of the COLREGs thus state that "In construing and complying with these rules due regard shall be had to all dangers of navigation and condition and to any special circumstances, including the limitations of the vessel involved, which may make a departure from these rules necessary to avoid immediate danger". A system with pre-programmed choices would, therefore, hardly be able to meet this wording.

Rule 5 of the COLREGs on lookout says that a proper lookout must always be maintained "by sight and hearing as well as by all available means." An electronic system that is to take over the lookout function would, therefore, have to demonstrate that it provides an equivalent situational awareness as a human lookout to meet the first part of rule 5. The second part is today interpreted as the use of available electronic aids, so there should not be any obstacle to integrating other sensors into the lookout function, as long as they provide at least an equivalent safety level.

The second part of rule 5 requires "a full appraisal of the situation and the risk of collision." This, like rule 2, points to a human decision-maker being part of the navigation but says nothing about this person needing to be physically present on the bridge.

COLREGs rule 6 and 8 also point to the need for simultaneous human competence in the ship's navigation. Both to assess safe speed and to meet the requirement of demonstrating good seamanship. Again, however, there is no requirement for this assessment to take place on the ship's physical bridge. It would therefore probably be compatible with the rules for the ship to be remotely controlled from land, as long as it is technically possible to create at least the same situational awareness as if one were physically on the ship's bridge.

In the event of a loss of communication between ship and land, the ships should be considered as not under command. Therefore, it will be necessary to ensure that the ship in this situation can comply with COLREGs rules 18 and 27.

From the above, we can see that there is nothing in the COLREGs that prevents the 3 use cases that this report addresses. However, there are other significant sets of rules, that deal with ship navigation, primarily STCW and SOLAS, which Denmark, as a flag state, has both ratified.

With regard to the STCW Code focus is on Part A, Chapter VIII *Standards regarding watchkeeping* (15), and like in COLREGs, function and simultaneity the fulcrum. For example, rule 14.1 requires *'continuous state of vigilance'* while rule 18.1 states that *'at no time shall the bridge be left*

unattended.' According to rule 15 *'the lookout must be able give full attention to the keeping of a proper lookout and no other duties shall be undertaken or assigned which could interfere with the task'*. Rule 24 stipulate, that *'the officer in charge of the navigational watch shall keep the watch on the bridge'* and '*in no circumstances leave the bridge until properly relieved'*.
It shall also be emphasized that according to the STCW convention VIII/2 (2.2.1) the officer in charge of the navigational watch shall be physically present on the navigation bridge or in directly associated location such as the chartroom or bridge control room.

These rules put a end to the concept of an unmanned bridge, both concerning the idea that, onboard officers can be on call and that remote operators can control several ships, simultaneously. However, they do not prevent support systems from assisting the duty officer (as in use cases 1 and 2). In terms of use case 3, it is a question of how, one understands the concept of "bridge". If one understands a bridge to be located on a ship, these rules prevent use case 3. If one understands a bridge by its function, as a place from which the ship can be controlled, the rules do not prevent use case 3.

The '*Standards regarding watchkeeping'* allows for the ship's bridge to be manned by one person (16), as long as a careful assessment of the situation has been made. Rule 16 lists the points to be considered in this connection. Additionally rule 17 lists the factors that are to be taken into account upon determining the composition of the navigational watch. The support systems from use cases 1 and 2 will according to .9, .10 and .12, justify a reduced bridge crew.
The watchkeeping regulation's rules 33 and 34 require the ship's equipment to be tested regularly during navigation, especially before expecting conditions that pose a risk to navigation. All existing equipment has such test functions built into their design, but it is likely necessary to impose new technical requirements on the equipment in cases, where the ship is controlled via remote control. In addition to the COLREGs and watchkeeping regulation requirements, there is a need for regulations regarding the technical approval of systems used in ship navigation. For instance, there must be requirements regarding the quality of electronic lookout, dependability and redundancy in communication systems used for remote controlling the ships, and the physical design of a remote-control bridge. This can either be done through SOLAS or, more likely, through classification societies. (17) In particular, SOLAS Chapter 5 (18), Rule 15 on bridge design, Rule 19 on navigation systems, and Rule 22 on bridge visibility may come into play. SOLAS Chapter II-I Rule

37 also states that there should be two independent communication paths between the bridge and the engine, something that can be challenging in ships controlled from land. The various chapters of SOLAS are also addressed in the chapter on technical conditions. Finally, shipping companies need to carry out risk assessments for the use of such equipment. This can likely be done within the rules of the ISM code. The ISM code is a framework regulation and is therefore well-suited to accommodate technological developments such as those addressed in the three use cases.
In conclusion, we can deduce that there is nothing preventing the three use cases in the COLREGs or the watchkeeping regulation. As long as the interpretation is that a bridge does not necessarily have to be located on the physical vessel but must fulfill the functions understood by a bridge in the two sets of rules. However, if one differentiates between the physical bridge on the ship and an electronic bridge on land, there will be several barriers in the current legislation, not least STCW VIII rule 2.2.1 and SOLAS II-I rule 37.

There will be a series of technical requirements for communication equipment, electronic sensors, and the design of an electronic bridge that need to be established, but this work is already underway within various classification societies.

3.3 The Crew's Role, Responsibilities, and Obligation

The requirements for the crew's education are governed by the STCW Convention. Article 3 states that it only applies to "seafarers serving onboard seagoing ships" and, therefore, it is not initially applicable to operators of remotely controlled vessels. However, the STCW Convention was written in 1978, with the latest revision in 2010, so it does not account for ships that might be remotely operated or unmanned.

Looking at the convention's broad purpose "to promote the safety of life and property at sea and the protection of the marine environment" and seeing that the convention allows for member states to make special rules to account for technological advancements, one would assume that the STCW Convention's guidelines would still apply to operators of remotely controlled units. This is supported by preliminary work in IMO, where it has been concluded that changes to education should occur within the framework of the STCW Code. (19)

In the current legislation, the ship's master, along with the shipping company, is the central responsible party, both in terms of criminal and civil law. Apart from the overall responsibility for the ship's navigation and seaworthiness, the ship's master also represents the shipping company and the flag state and has the right to enforce the flag state's rules on board the ship. The ship's master is also responsible for the crew, passengers, cargo, and represents the shipping company and flag state to the authorities.

In practice, many of the ship's master's tasks have been relocated onshore or assigned to the shipping company's agents in the port. The ISM Code recognizes this intersection by requiring the designation of a "designated person" as a link between the ship and land organizations.
The aforementioned conditions do not have a significant impact on the first two use cases examined in this report, as both the crew's educational requirements and the role of the ship's master remain unchanged. However, regarding use case 3, where there is no longer a crew on board the ship, changes to the ship's master's role will be necessary, just as there is a need for new initiatives in terms of education and qualifications for the operator.
The current legislation regarding the ship's master largely assumes that he is physically on board the ship. For example, the Danish Merchant Shipping Act § 135 mentions that the ship's master must not leave the ship in an emergency unless there is serious danger to his life, while the Danish Act on Safety at Sea § 10 requires ship's masters to ensure that technical installations on board the ship are in proper condition and operational. The Danish Act on Seafarers' Conditions of Employment also stipulates that there must be a master on board all ships, and the crew necessary for the safety of human life at sea. (20) These rules pose a barrier to use case 3 in this report and for remotely controlled ships in general.
The parts of the ship master's role related to navigation obligations, as well as the role as the ship's and shipowner's representative, will likely be filled by a remote operator if he/she has the necessary education. The same applies to the ship master's reporting obligations to national authorities. (21) However, other roles, such as the ship master's obligations towards those in distress at sea or obligations to customs authorities, will be difficult for a remote operator onshore to fulfill. Therefore, changes will need to be made to these rules or exemptions granted if the rules allow for this.

Additionally, questions arise about the responsibility for the ship's seaworthiness. Currently, this responsibility lies with the ship's master (22) regarding onboard conditions, while the shipowner is obligated to ensure that the ship's master can fulfill his obligations and is responsible for ensuring that the ship is inspected and has valid certificates. (23) For a remotely controlled vessel, it would be more natural for the entire responsibility for the ship's seaworthiness to rest with the shipowner, as they have the ability to influence conditions.

Regarding the ship master's role as a representative for the shipowner with cargo owners and national authorities, it would also be more natural for this to be delegated to a representative appointed by the shipowner, just as it happens in practice for many types of ships today.

In summary, we see that the current role of the ship's master will need to be divided between the remote operator, the shipowner, and local representatives in the port. This will require changes to current legislation that reflect this division.

In addition to the remote operator's role as captain, they also play a central role in the ship's navigation. To fulfill the COLREGs requirements for good seamanship, it can be assumed that at a minimum, they should possess the same competencies as a navigator trained under the STCW convention. Furthermore, there are specific skills associated with the remote control of a ship, notably knowledge of communication equipment, sensor technology, and remote-control technology. A new training program should be developed to reflect the unique combination of the requirements from the STCW convention and this new technology. Special attention should be given to how current requirements for time at sea and ship sizes are best represented in such training. Another question regarding the remote operator is the maintenance of skills after training completion. Current requirements for time at sea might need to be supplemented with recertification requirements, similar to those seen in aviation.

There's also the matter of the remote operators' employment conditions. They cannot be considered as seafarers based on the current definition in the law concerning seafarers' terms of employment (24) and would likely be regarded as salaried employees. At the same time, a land-based remote operator wouldn't be able to earn a net wage under the current system. (25) These changes might impact the commercial aspects of the remote operator's job.

3.4 Technical conditions onboard remotely controlled ships

Specifically, for use case 3, which involves a remotely controlled drone, there are multiple areas in legislation that poses barriers when looking at the technical equipment onboard the ship.
Beyond the previously mentioned technical challenges concerning the approval of electronic lookout and navigation systems, three areas, in particular, raise concerns. The first in the ship's (and crew's) obligation to provide assistance during maritime emergencies. The second is related to environmental pollution from ships, which requires an immediate local response from the vessel. The third pertains to the SOLAS requirements for the ship's technical equipment.
Several legal provisions oblige the captain and the ship to assist those in distress at sea. (26) This is also a fundamental aspect of the maritime rescue services of all countries. Where the obligation to report about those in distress at sea can be met by an unmanned remotely controlled ship, the situation is different regarding the duty to provide assistance. The wording of the rules can be interpreted to mean that one only has to provide the assistance one is capable of, and if an unmanned ship is not capable of providing meaningful help, it isn't obligated to do so. If this interpretation is adopted, the rules are not an obstacle for use case 3. On the other hand, the duty to provide assistance at sea is one of the absolute cornerstones of maritime safety. Therefore, questions might arise about whether a state would accept that unmanned ships don't contribute to this. If the ships are to provide a level of assistance comparable to a manned ship, it requires technical solutions onboard, along with a new set of regulations or relevant amendments to existing rules.

Regarding environmental pollution from ships, the MARPOL convention, and its Danish Implementation (27) requires ships to have emergency response plans. These plans assume there is a crew onboard to address the pollution and collaborate with the authorities. For remotely controlled ships without a crew, this poses a barrier, necessitating a technical solution that matches the current response level (principle of equivalence). Maritime environmental legislation also requires ships to report observed pollution, just as SOLAS imposes similar requirements concerning the loss of hazardous goods at sea. This will also demand a technical solution onboard unmanned ships, enabling them to detect and report such observations on par with manned ships.

SOLAS imposes a wide range of requirements concerning ship construction and onboard equipment, which can create obstacles for an unmanned vessel. Some of these arementioned below, but more could be identified with a closer examination of the code and all its associated codes. The IMO's analysis elaborates on these more detailed in annex 1, but even here, it is acknowledged that a complete overview of the barriers doesn't yet exist.

SOLAS Chapter II-1 regulation 19 mandates the presence of damage control plans on the bridge. regulation 38requires machinery control alarms in the control room that can be heard in the accommodations, something similar is required in regulations 51 - 53. Regulation 49 mandates that the machinery settings be visible... 'from the navigation bridge'. All of these regulations require clarification of what is meant by terms like the navigation bridge, similar to the issues in relation to watchkeeping. SOLAS Chapter II-2, and its accompanying fire safety systems code, contains detailed requirements for fire protection and firefighting. Common to these rules is that the crew plays a key role, both in the detection and fighting of fires. Even if the ship no longer has a crew onboard, and therefore there isn't a risk for them, there's still a risk concerning potential cargo, other ships, and the surrounding environment. For remotely controlled unmanned vessels, there's a need to determine how SOLAS Chapter II-2 can be complied to or how an equivalent safety level can be achieved. SOLAS Chapter III deals with rules for lifesaving appliances on ships. Here too, the underlying philosophy assumes that there's a crew onboard. For instance, regulation 10.3 requires that there are sufficient crew members onboard to evacuate the ship and operate its rescue equipment. According to regulation 19 crew training and drills onboard are mandatory. Again, clarification is needed on how these rules should be interpreted concerning an unmanned ship. This is also linked to the previously mentioned issue about maritime rescue operations.

SOLAS Chapter IV deals with radiocommunication. Here again, there's a requirement for an onboard crew to operate the communication equipment. Contrary to the other chapters in SOLAS, the rules apply even to ships as small as 15 meters in length, so even smaller drones would have to comply with this chapter. Regulation 12 requires a continuous watch on certain frequencies, while regulation 16 requires at least one person onboard to be qualified to operate the radio equipment. While it might be possible tomaintain the watch from a remote-control room, regulation 16 poses a barrier for remotely controlled ships.

SOLAS Chapter XI-2 contains the requirements to enhance maritime security. Here, regulation 6 requires that the ship is equipped with an alarm system that can be activated from the bridge and at leastone other place onboard. However, regulation 12.1 allows the flag state the right to grant exemptions from the regulation if an alternative system can demonstrate equivalence.

A commonality among most of the mentioned issues is that, internationally, SOLAS only applies to ships over 500 GT. However, for Danish flagged vessels below 500 GT build after 2001 SOLAS Chapter II also applies. SOLAS Chapter I applies to Danish flagged vessels of more than 15 meters in length.

According to Danish legislation, the administration can grant exemptions from SOLAS if the ship can demonstrate an equivalence. According to SOLAS Chapter I regulation 4(b) the Administration may exempt for provisions of chapters II-1, II-2, III and IV (design requirements). (28) However, an equivalent level of safety shall be demonstrated.

4 Conclusion

From the above review, we can conclude that there is a clear distinction between the first two use cases and the third. As long as the crew remains on board and the systems limit themselves to support in the style of already existing systems such as RADAR and ECDIS, there are only limited obstacles to implementation in current legislation. The challenges arise around the technical approval of the systems' capabilities. The documentation for meeting the equivalence principle in situations where the systems are to replace already existing solutions, primarily in relation to the auto lookout system. And the necessity to retrain the staff who will work with the systems. In relation to use case 3, on the other hand, there are extensive challenges in current legislation. Basic questions about the captain's role, responsibilities, and rights remain unanswered. For example, how should the captain fulfill a number of his obligations when he is not physically on board the ship? Also, questions about obligations in relation to reporting duty, maritime rescue, and representation need clarification. There are also outstanding questions regarding the education and qualifications of a remote operator, as well as clarifying the remote operator's status as a seafarer or not. In relation to the conduct of sailing with an unmanned remotely controlled vessel, there are fewer challenges with the COLREGs, primarily in relation to the understanding of terms in a situation where the master is not physically on board. There are bigger problems with the watchkeeping ordinance which in its current form does not allow for remote control of the ship's bridge. Here, changes will be needed.

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Chapter 2

Safety and Risk Assessment in relation to autonomous vessels

By Signe Jensen, SIMAC (sje@simac.dk)

1 Introduction

Maritime safety is described as a state where human activity does not pose a danger to either people, property, or the environment. (1) It can be divided into four essential areas, each of which also constitutes a regulatory field. The following figure illustrates the division of Maritime Safety into the four areas: navigation, technical and operational, environment, and sea rescue.

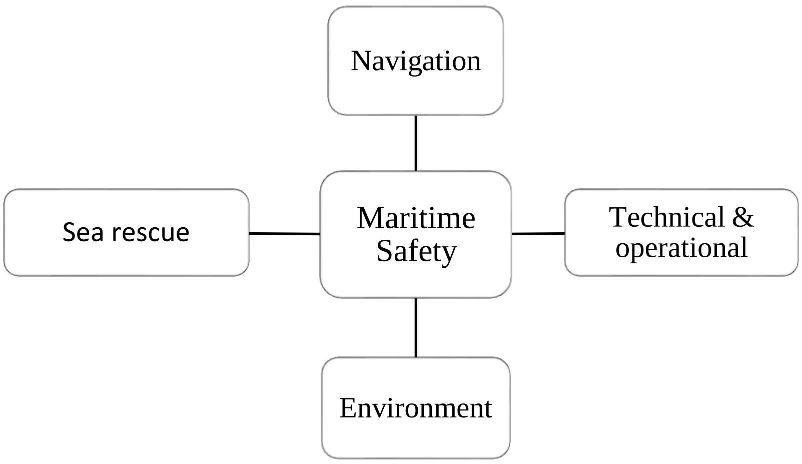

Figure 1: Maritime safety divided into areas.

The concept of *safe navigation* includes sailing a ship safely from point A to B, i.e., the voyage is conducted without causing harm to property, people, or the environment. This includes elements such as maneuvering and anti-collision. Navigation is primarily regulated through SOLAS Chapter V, while the competencies a navigator must possess to handle the navigation of a ship are described in the STCW Convention.

Technical and operational safety covers the part operation of a ship that does not relate to the ship's navigation. The nature and handling of the cargo pose risks for both the ship and its crew, as does the management of the propulsion system. Thus, the safety of these operations for ships and humans falls under this area. It is important to note that maintenance is an essential tool for ensuring a high level of safety, just as knowledge and competencies also contribute. Therefore, it is regulated through SOLAS, with best practices described in various codes (2) as supplements to SOLAS and STCW, which describe competency requirements for the areas. Additionally, shipping companies also set up their own systems and requirements to manage the risk, both due to industry requirements and as a result of the International Code for the Safe Operation of Ships, the ISM Code.

Environmental safety is also an area within the safety concept. The operation of the ship should occur without unnecessary impact on the environment. Ships must follow the international regulation for pollution prevention, MARPOL, which establishes the limits accepted by the international community for emissions to the environment. This includes the requirements for equipment, construction, and reporting to reduce the risks associated with the operation of the ship. This point is debated, as in certain cases it can be deprioritized if there is a danger to human life. Thus, many working on reducing fuel consumption are faced with questions about whether safety has been considered, understood as safety for the ship and life, even though the optimization itself can be seen as taking care of environmental and climate safety. This is an expression of the safety hierarchy that prioritizes human life over the environment.

Search and rescue are the last area, initially concerning the people on board a ship, where there are requirements for handling and protection in various situations. Fire on board, man overboard, and evacuation are situations regulated in SOLAS where people on board are exposed to a particular risk, which can be reduced with equipment and training. It should be noted that part of the safety system also includes ships being obligated to assist each other in connection with sea rescue. Thus, this is also an aspect to consider when conducting a risk assessment. The Polar Code is an example of this, where ships sailing in polar regions cannot expect to have the same access to evacuation assistance from other ships or land stations. Therefore, higher demands are placed on them to be self-sufficient for extended periods.(3)

When assessing the safety aspect, it is necessary to consider all four areas. According to the requirement for documentation of equivalence, it is crucial that a risk assessment covers all four areas, and through this, it can be documented that an autonomous system does not pose a higher risk than what is accepted in a conventional system.

2 Method

Maritime safety is as described in the introduction, a state where an activity does not pose a danger to people, the environment, or property. A risk assessment evaluates the risk that a human activity represents and whether it is associated with a danger to people, the environment, or property. There are numerous models for risk assessment, including technical, economic, political, and more. These can be based on both qualitative and quantitative methods. The IMO has developed a guide for the Formal Safety Assessment (FSA)(4), a process based on five steps where step 2 is the actual risk assessment. The five steps are described as follows:

1. First, hazards are identified.
2. Then, a risk analysis is conducted.
3. Based on the results of step 2, the options for controlling and reducing the identified risk are explored.
4. A cost-benefit analysis (cost versus risk) is prepared.
5. Based on the above, a recommendation is made for decision-makers.

It is IMO's guidance for the FSA that forms the basis for the methodological approach in this report. It is important to emphasize that the FSA was developed as a tool to evaluate new regulations to ensure that the drafting and adoption of new regulations occur on an informed basis.(5) In addition to the guidance, a process diagram has been developed (see Figure 2) targeted at the decision-makers in IMO. Since autonomous systems must demonstrate equivalence with existing regulations, it is assumed that by using the FSA as a methodological approach, it will strengthen the documentation. This report will not produce a complete FSA as this would require specific system knowledge. However, it will exemplify in individual cases the hazards that can be identified based on existing regulations and current research in the field.

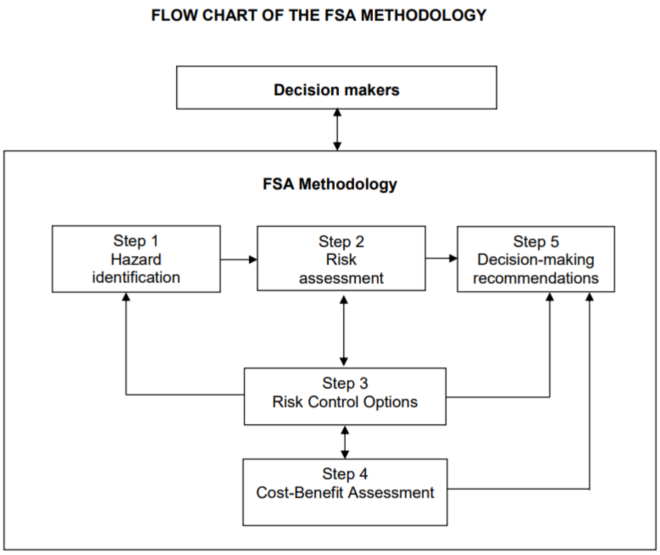

Figure 2: Process diagram for IMO's FSA(6)

This sub-report thus bases its approach on a risk assessment that relies on a rational line of thought where the acceptable risk is determined based on a quantitative assessment. The risk analysis itself will therefore be based on a probabilistic approach, where the risk is assessed from two elements: the probability of occurrence and the extent (accident size). This approach to risk assessment is often associated with a risk matrix, as illustrated in Figure 3, and is termed a quantitative approach since data for probability and extent often rely on historical statistical data, but it can also be based on hypotheses.

Hyppighedsklasse	Hyppighed pr. år	Uheldsstørrelse				
		Uønsket hændelse Højst små materielle skader	*Lille uheld* Mindre arbejdsskade i virksomheden	*Alvorligt uheld* Alvorlig arbejdsskade i virksomheden	*Stort uheld* Dødsfald indenfor, skadede personer udenfor virksomheden	*Katastrofe* Dødsfald udenfor og indenfor virksomheden
Hyppigt Vil ske flere gange under installationens levetid	$1\text{-}10^{-2}$	B, D, F			Høj risiko	
Sandsynligt Vil sandsynligvis ske, men ikke nødvendigvis	$10^{-2} – 10^{-4}$		H	A, C		
Ikke sandsynligt Kan muligvis ske	$10^{-4} – 10^{-6}$	I			E	
Meget usandsynligt Næsten utænkeligt	$10^{-6} – 10^{-8}$					
Ekstremt usandsynligt Hyppighed er under rimelige grænser	$< 10^{-8}$	Lav risiko				G

Figure 3: Example of a Risk Matrix from the Environmental Protection Agency, relating to acceptance criteria in Denmark and the EU.(7)

This model is often used as a basis for regulation, as is also the case with IMO's FSA. An example can be given with the damage stability regulations. Here, construction requirements are determined based on ship accident data, which is used to establish the probability of damage at a specific location on the ship. While the effect of such damage can be calculated based on the actual ship's data, approval is then based on an acceptable risk reflected in the regulations. What this acceptable risk is will ultimately be a political decision. From the automotive industry, it is known that the tolerance for errors in autonomous systems is very low. Where a level of accidents due to human error is accepted, there is zero tolerance for AI. This is even though a number of actors argue that AI does not lose concentration, fall asleep, or drive under the influence of substances, all situations that are documented essential causes of accidents. (8) Therefore, it is not the task of this report to assess whether a risk is acceptable. The focus is on identifying and reflecting on risks. The method used for identification was first a brainstorming session conducted at a workshop. (9) The next step was to analyze the regulation relevant to the operation, which was considered as an expression of the regulator's view on risk. At this stage, knowledge from previous projects in the area and workshop one, both described in more detail in section 4 on methodology in the framework description, was also included. The workshop uncovered several safety concerns in relation to the cases presented in the framework description. It should be noted that the environmental aspect is included in the current report since, as described in the introduction, it relates to the concept of risk. The statements were sorted in the table below in relation to which safety concept they concern/influence/impact. The following sections will address the individual cases.

	Auto-lookout	Auto-speed	Auto-dock	Full autonomy (MASS 3)
Navigation	Missing small objects Who gives the order? Competence needs Can it listen? Support system or decision support/potential to improve safety	Anticollision (keep course and speed) Adapt to traffic in the area Interconnection with auto-lookout Safe speed What if navigator dies or passes out Who decides if there are different perceptions of a situation (safe speed)	Wind and weather (who decides window of operation) Anticollision (how does other ships react) Maintain the navigator's competences Time Actual weather observation or a forecast being used.	Coding – Recognition Data i.e., weather data Data processing – speed/amount/delay
Technical/ operational	Redundancy Can the sensors be kept clean?	Damage on sensors sensibility Dependence on connection	Reference systems stability and reliance Types of sensors	Reliance of connection to remote control center (connectivity)

	What happens if connection is lost Systems need to work together Competence needs			
Environment		Route optimization Bunker spending Bird protection	Sensors for the surrounding environment Is environmental approval required?	
Sea rescue	Manning in emergencies			

3 Risk Assessment of Auto-speed

COLREG (10) applies the concept of 'Safe speed' in accordance to Rule 6 in which it is stated that; *"Every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions"*

Unlike on land, where speed limits determined by a comprehensive, national risk assessment, at sea, the navigator determines the safe speed based on the prevailing circumstances and the ship's characteristics.(11) A list of factors considered in determining safe speed is mentioned in COLREG Rule6 (a) and (b). The draft in relation to the available water depth (Rule 6 b(vi)), the ship's maneuverability (Rule 6 a(iii)), and wind, sea, and current conditions are essential for systems focusing on using auto-speed systems to optimize ships' energy consumption. (12) Adjusting the ship's speed to avoid unnecessary fuel use, as shown in figure 1, is a safety aspect related to the environment. However, this is just part of the assessment of safe speed. As indicated in ECOPRODIGI / EXOPRODIGI's report on Højestene ferry (13), traffic density and the need for maneuvering affect the speed required to follow the ship's schedule, and thus the optimal speed in relation to consumption. Visibility (Rule 6 a(i)), traffic density (Rule 6 a(ii)), and the sea, weather, and other disturbances (Rule 6 b(iii)) are factors that influence the ability to form a picture and understanding of a given situation (situational awareness) and thus an understanding of what safe speed is in that situation. It is complex and varies; furthermore, experience also plays a role in assessing safe speed. Time is a crucial factor in determining what safe speed is. The time from detecting an object to the moment action must be taken to avoid an unintended incident should be long enough for the information to be processed, analyzed, and translated into action. In a MASS 1 ship, this process will be performed by a navigator, while it is executed by a system in other MASS ships. The concept of safe speed is closely related to the lookout, which is addressed in Rule 5 of COLREG and the analysis required to assess the risk of collision, Rule 7 of COLREG. Section 4 will address the concept of lookout, while the analysis is discussed in section 6, as this part of the process relates to the auto-anti-collision system.

Several projects have worked with auto-speed, primarily focusing on energy efficiency, as optimal speed relates to fuel consumption.

Project name	Aim	Link
ECOPRODIGI / EXOPRODIGI	Developing a decision support system for energy efficient ship operation. .	https://ecoprodigi.eu/publications
Via Kaizen	To develop AI technology for semi-autonomous route planning. Note: route planning is a gray box that both relates to the surrounding	https://yaramarine.com/vessel-optimization/via-kaizen/

	environment, current schedule and the ship's data. The system implemented and tested (crew on board – decision support)	
Stena Fuel Pilot	Development of AI technology for crew decision support related to fuel consumption (2019 –2021) .	https://www.stenaline.com/media/stories/ai-assisted-vessels/

Based on experiences from projects and the concept of safe speed, several risks associated with this element must be defined, and the following must be considered:

1. Information – Does the auto-speed system decide to change speed on its own without warning first? (Changed speed affects the risk of collision and is therefore essential in the analysis)
2. Information – Does a change of speed require approval from the operator/navigator; is the system allowed to conduct minor changes, and how significant change would require approval from operator/navigator? (Risk of information overload – too much information can lead the navigator/operator to ignore the auto-speed and just accept the speed change)
3. Coordination – Is auto-speed an independent system? (Risk associated with yet another system that the navigator/operator must monitor)
4. Coordination – Is auto-speed part of the existing systems? (Is there a need for information exchange between systems?)
5. Lost signal – If auto-speed loses information, what is then the course of action? (Stop the ship? Hand over to the operator/navigator? In both cases, there is a time aspect to consider)
6. Maintenance – Updates? (Time-based or condition-based?)

The identified hazards and resulting risks are at a high level and are not system specific. It's essential that an FSA (Formal Safety Assessment) is carried out for each system and also at an overall level. Point 6 concerns maintenance, which is separately addressed in the chapter 5 on Maintenance.

4 Risk Assessment of Auto-lookout

The lookout is tied to the concept of safe navigation, and its purpose is described in the regulation. A proper lookout shall according to STCW Code chapter VIII Standards regarding Watchkeeping 4-1 (14) serve the purpose of:

.1 maintaining a continuous state of vigilance, by sight and hearing as well as by all other available means, with regard to any significant change in the operating environment.

.2 fully appraising the situation and the risk of collision, stranding and other dangers to navigation; and

.3 detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.

Chapter 1 on legal barriers to autonomous ship operations, established lookout as a key barrier for MASS 3 ships.
Point of departure for the risk assessment of the electronic lookout, is the existing requirements for the human lookout. Also, there is a significant difference between an auto-lookout as a support function, with a navigator attending the bridge, where the auto-lookout is an additional function, or a MASS 3 ship, where the electronic lookout is part of a system that along with other systems replaces the onboard navigator.
As mentioned above, the proper lookout has three key functions. Ad .1 and .3 relate to object detection; hence a risk assessment would focus on the automatic lookout's ability to detect and identify objects, especially under varying weather conditions and reduced visibility. According to ad. 1, both sight and hearing are essential when maintaining a proper lookout. This was also addressed at Workshop 1. Consequently, the first step is to evaluate the auto-lookout's ability to; (a)

detect the object; (b) identify the object; and, (c) adapt to the existing weather conditions (e.g. reduced visibility). According to ad .2 the ability to analyze the situation is essential. Onboard a conventional ship (MASS 1), this task is performed by the navigator. Based on the inputs available the navigator assess the situation and acts accordingly. (14) Still, it is important to consider how, and which information is presented by the auto-lookout to the navigator. Onboard a MASS 3 vessel it is assumed that the system will assess the situation and act accordingly, but that there is a ROC operator that if the system fail will take control as the 'navigator', therefore it is important to consider how information is presented and which information is presented, for the operator to be able to with a short notice take control and handle the situation. This is crucial part of the risk assessment as the information from the auto-lookout forms the basis for the navigator's analysis.

At workshop 1, some of the participants argued that a auto-lookout might be considered safer than a human lookout. The participants posited that a human lookout has a tendency to become inattentive and distracted and their field of vision are limited to one direction at the time. In contrast, a digital lookout would neither become inattentive nor distracted and would be able to "look" in its entire field of vision simultaneously. The HUMANE project identified similar perspectives related to the lookout function. (15) The respondents participating in the HUMANE project reflected on the human lookout's ability to concentrate and the concept of tunnel vision. This risk has also been raised by current regulations, e.g., Volume III of the International Aeronautical and Maritime Search and Rescue (IAMSAR) manual. Section 2.15 states that one should be aware of the risk of look-out fatigue during search and rescue operations. Factors affecting a lookout's effectiveness are described in Appendix C to IAMSAR Vol III. A key concern raised is that the eye only sees what our brain allows us to see. That means a lookout only sees what the person is coded to look for. In this respect, an auto-lookout resembles a human one. The assumption that an auto-lookout can be more effective is thus supported by Appendix C to IAMSAR vol III, but only if it is coded to see and identify sea objects. A raised question is whether it is capable of, or should be able to, highlight objects that the system cannot identify and how it communicates this either to a navigator on the bridge or an operator on land.

Several risks associated with this element can be identified:

1. Information – Should the auto-lookout itself filter out relevant objects and only forward information about these? (Risk of under information – missing information can lead to a misanalysis of a situation)
2. Information – What happens if the auto-lookout provides information about all observed objects? (Risk of over information – too much information can lead the navigator/operator to ignore the auto-lookout and not use the information for their analysis)
3. Coordination – Is the auto-lookout an independent system? (Risk associated with another system that the navigator/operator must monitor)
4. Coordination – Is auto-lookout part of the existing systems? (Is there a need for information exchange between systems, does the lookout only provide information or does it also receive?)
5. Maintenance – Sensitivity of sensors to weather conditions (Dust, saltwater, waves, vibrations, accelerations - how is the auto-lookout affected?)
6. Maintenance – If there are degradations, how is the warning system set up? (Will the navigator/operator receive a warning, and is there then an option for a human lookout to take over?)
7. Maintenance – Condition-based or planned maintenance? (Can the sensors be cleaned during the journey, or does it need to be done in port, can it be done automatically or manually?)

Points 5, 6, and 7 are addressed in chapter 5 on maintenance, although they are also mentioned in this chapter as they are crucial for a risk assessment.

5 Risk Assessment of Auto-docking

While the systems auto-lookout and auto-speed are tied to the existing regulation, docking a ship at a quay is not specifically regulated. However, it is a complex maneuver that requires the navigator to be well-acquainted with the ship's maneuvering characteristics and can relate these to external influences such as wind and current. This operation requires experience and is therefore carried out by an experienced navigator. Even though maneuvering is trained in bridge simulators during education and taught theoretically about the forces affecting the ship, the final training to perform this task is often onboard side-by-side training. There is an increased risk of property damage associated with this operation.

Several auto-docking systems are on the market. SmartDock, developed by Wärtsilä, is one of them. The system Wärtsilä developed is based on known automation and positioning systems, the so-called dynamic positioning systems that have been used in the offshore industry (and in the cruise industry) for a long time. The system can maintain a ship in a specific position with a fixed course by combining data from sensors (movement and wind, among others) with data from nautical systems (position and course, among others) and control of propulsion and maneuvering equipment (thrusters and rudder, among others). This is what SmartDock uses.

During Workshop 1, several risks were highlighted by the participants. One point emphasized was anti-collision. Today, there is full surveillance by a navigator when the ship is on DP (Dynamic Positioning), and in this context, it is the navigator's task to ensure against and intervene if there is a risk of collision. Similarly, one could think that this is the task of the navigator/operator in an auto-docking system. However, this requires maintaining the navigator's competencies if they are to intervene if the situation becomes too complex, and the auto-docking system cannot dock the ship, or another unexpected situation arises. We know that maneuvering requires experience, so how is this ensured if daily operations are handled by an autonomous system? Thus, with this system, several risks are identified:

1. Competence Loss: If the navigator is perceived as the last barrier, it is essential to ensure the skills to maneuver the ship are maintained.
2. Unexpected Objects: Will sensors detect unknown objects, how does the system react to, for instance, accumulated trash/plastic?
3. Operating Window: Who decides if the weather is too "rough", is it coded in the system? Who codes, and what about the shipmaster's decision-making competence?
4. Data: How valid is the data? In a harbor environment, wind and current are not constant, and a delay in the signal can, therefore, be catastrophic.

In addition to the risks mentioned above, there is also a concern directed towards the maintenance of sensors and thereby the risk of outages or faulty signals. Also, a risk assessment will be influenced by the dependence on signals from other systems, e.g., whether there is an auto-lookout or a navigator who ensures the lookout.

6 Risk Assessment of Auto-navigation and Auto-anticollision

For the fully autonomous ship, MASS3, the systems of auto-navigation and auto-anticollision are essential. Several projects have worked on getting these two systems to function, thus achieving a MASS3 ship. The legal barrier associated with responsibility is omitted from this part report, as it is described in part report one. It was identified during a roundtable meeting that this barrier, regarding who bears the responsibility when an incident happens, occupies a significant concern. This ties to the risk concept which addresses; who carries out and takes responsibility for the analysis of a given situation as well as the resulting action. For simple situations, the system can be coded for recognition and action (this could be a fallback state within the Operational Envelope). The question arises for complex situations where there is no "correct" action as per current legislation, but rather a choice between several appropriate solutions, each with a negative consequence. Is it possible to code the system with the an optimal action within a worst case scenario – and who is responsible?
An example of a simple complex situation is a risk of collision in a narrow channel between a ferry and a gas tanker. If the two ships collide, there is an increased risk to human life due to the nature of the two types of cargo. In a situation like this, the optimal action might be to ground the ship, depending on the seabed's nature and weather forecast, while traffic density might also influence the action. The solution depends on how the situation is perceived, and it might be possible that the solution of an autonomous system is the most optimal, but a legal entity is necessary. This poses a challenge with regards to the MASS3 ship.

Several trials are underway in Scandinavia with fully autonomous ships. So far, GreenHopper is the only Danish concept in operation. GreenHopper is a ferry across the Limfjord, currently in a trial phase, laying the foundation for future approval to sail without a navigator onboard. A risk assessment for the ferry has been drafted as part of the project (see https://shippinglab.dk/workpackages). The risk assessment highlighted that especially sea rescue poses a significant challenge that is hard to address. This ties to passenger transport and the resultant low risk acceptance. GreenHopper is designed for the MASS3 level, with the possibility for a land-based operator to act as backup to the system once the ship sails without a navigator onboard after the test period.

The container ship Yara Birkeland is a Norwegian project, where they have designed and built a smaller container ship to relieve inland road transport. The 80-meter-long container ship sailed with a crew onboard in 2022, and during 2023 and 2024, the plan is to gradually implement and test autonomous functions. DNV is involved as a supervisory authority in the project, aiming to demonstrate that it is possible to operate an unmanned ship supported by a land-based operator, i.e., a MASS3 ship. For more information about the ship, see (https://www.kongsberg.com/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/)

Zeabuz ([https://www.zeabuz.com/) is another Norwegian MASS3 project. It is a spin-off from a research project conducted by NTNU in Trondheim. The purpose was to design, build, and test a prototype for an autonomous city ferry. It is a small passenger ferry intended to be part of the infrastructure in larger port cities. It was tested in Trondheim over a 3-week period in September 2022 and is set to operate in Stockholm in the summer of 2023. The risk assessment at the system level is not available for a project like Zeabuz, but they have pointed out in conference presentations several challenges tied to the lack of a clear definition of hierarchy and decision-making competence for a MASS3 ship. Zeabuz identifies four agents(16): (a) the autonomous system, (b) the onboard observer (for the time being, at least), (c) the land-based operator, and (d) the technical support center. (c) and (d) are comparable to the captain and chief engineer, respectively, but on land. Zeabuz emphasizes that two elements need to be assessed and aligned: action (who initiates and carries out an operation) and authority (who is responsible). As it stands today, we know the distribution of competencies as it is reflected in regulation. We also know, for instance, that there can be doubt when the ship's captain is on the bridge, which can result in the watchkeeping navigator not taking action. Therefore, situations with multiple actors on the bridge are considered high-risk situations, requiring explicit communication about the distribution of responsibility, just as there's training in Bridge Team Management. Similarly, this needs to be clarified when the four agents interact.

In Sweden, the Swedish Traffic Administration's ferry shipping company has ordered two so-called "smart ferries" prepared for MASS3. There is currently no experience with these, but a preliminary investigation has been conducted, and the results are in a report titled " *Drift och operation av smarta fartyg"*. (17) It has investigated the changes in operation and competence needs, elements resulting from a risk analysis.

Scandinavian experiences show that testing MASS3 ships is necessary to determine if the expected risk picture corresponds to what is experienced and if the control measures implemented to reduce identified risks are justified and comprehensive. This is essential work since we cannot draw on historical data when assessing probability and extent. Analyses and assessments of these autonomous systems are based solely on Work as Imagined (WAI). Only through testing can this be transferred to Work as Done (WAD) (18), allowing the procedures and control measures designed in step 3 of the FSA (see Figure 2 Process Diagram for IMO's FSA) to be adjusted. Thus, the FSA needs to be conducted at multiple levels and rounds.
Figure 4 proposes a validation process that accounts for the lack of historical data. The highlighted elements are what is deemed essential for a given FSA. The FSA is drafted on all four areas: (i) the individual system; (ii) the integration between individual systems; (iii) integration between system and human; and (iiii) integration between ship (human and system seen as a unit), the surrounding environment, and external operators. In the initial FSA, it is based solely on a WAI, where simulation (19) (concept testing) will allow for the testing of integration between systems, giving insight into WAD. Depending on the test setup, integration between the system and human can also be included, albeit with the caveat that it is in a simulated environment, which can affect human behavior. After simulation, an FSA may lead to changes and adjustments before testing in a protected test area can be carried out, focusing on integration between systems and up against humans. This forms a clearer picture of WAD, though without external actors. In this environment, any external actors would be familiar with the test, so it is still WAI. Only at the last point in the process will this part of the risk assessment be in focus.

Proposals for validation process				
Initial FSA (WAI)	System level	Integration between systems	Integration between system and human	Integration between ship (system+human) and surrounding environment/external operators
FSA after desktop (or simulations) test	**System level**	**Integration between systems**	(Integration between system and human)	
FSA after test in protected environment (test area)	System level	**Integration between systems**	**Integration between system and human**	(Integration between ship (system + human) and surrounding environment/external operators
FSA after test in environment (WAD)	(System level)	Integration between systems	Integration between system and human	**Integration between ship (system + human) and surrounding environment/external operators**

Tabel 1 Proposal for validation process

7 Consideration for a Future Risk Assessment Model

Currently, several guidelines have been developed for the creation and approval of Maritime Autonomous Surface Ships (MASS). Some of these are described below:

MASS UK Industry Conduct Principles and Code of Practice 2021(20): This UK industry guide aims to provide practical guidance to those who design, build, and operate autonomous and semi-autonomous MASS below 24 meters in size. While ships under twenty-four meters do not typically need to adhere to conventions like SOLAS and MARPOL, the code's objective is to ensure equivalence with internationally recognized regulations. While the code does not support the identification of detailed risks associated with individual operations, it helps form the framework for organizations looking to develop or operate these types of vessels.

EU Operational Guideline for Safe, Secure and Sustainable Trials of Maritime Autonomous Surface Ships(21): This EU guideline aims to support the harmonization of the approval process for testing areas. It is primarily targeted at the administration, i.e., the approving party.

Study of the risks and regulatory issues of specific cases of MASS (SAFEMASS)(22): This study was conducted by DNV GL at the request of EMSA. The purpose of the study was to identify risks and regulatory gaps associated with the implementation of MASS. The study concludes that the phenomenon of "*the ironies of automation*" remains a challenge for MASS. This perspective describes the inherent conflict in the goal of increased autonomy: to reduce risks associated with so-called human errors. The challenge lies in making systems so reliable that humans can be entirely removed. If this is not achieved, the human is left to intervene when autonomy fails.

Risk Based Assessment Tool (RBAT)(23): DNV GL has been developing a risk assessment tool for MASS ships since August 2020. The tool's primary purpose is to assist the EU's maritime administrations in the coming years when they have to approve MASS vessels, ensuring a uniform process in the EU. The process is broadly described as:

1. Describe the use of automation (and remote control).
2. Conduct a hazard analysis.
3. Perform a mitigation analysis.
4. Evaluate risks.
5. Address risk control.

Each point is further described in the RBAT *third report*. An essential aspect not presented in the FSA is describing the purpose of the automation. This is crucial for identifying and analyzing hazards and evaluating risks. It is essential to continue monitoring the ongoing work with RBAT, especially within the MARS project.

By combining RBAT with the validation scheme (Table 1 proposal for validation process), a documentation process can be established. This allows insurance and regulatory bodies to evaluate a project on an informed basis. Hence, it is recommended to continue developing such a tool to establish a model for the validation and approval process.

Chapter 3

Cyber and Information Security

By Signe Jensen, SIMAC (sje@simac.dk)

1 Introduction

Automation, digitalization, and increased communication connections to ships have meant that, where ships previously largely functioned as physically isolated operational units, where propulsion and navigation systems were not internet-connected to an administrative system, today they are largely connected to, among others, the company and suppliers. This has provided better access to monitor and update systems, which is essential for a number of optimization processes. However, at the same time, it has the downside of increasing the risk of, and vulnerability to, cyber-attacks.

In connection with the MSC's (1) regulatory scoping exercise (RSE), a number of potential challenges and areas were identified where it was estimated that there was a risk associated with a lack of regulation. Consequently, 'Cybersecurity and Connectivity' is pointed out as a risk area about which it is stated:

"*In addition to the common potential gaps and themes provided in section 3 of this report, the following items were raised by some Member States: connectivity, cyber security, information, watchkeeping and the implication of MASS on search and rescue as possible common potential gaps and themes.*"(2)

The areas highlighted here are also the barriers that were emphasized during the first MARS workshop. This applies both in connection with the autonomous subsystems that this report deals with, but also especially if one wishes to connect the systems in such a way as to achieve remote autonomy (MASS 3). The barriers that pertain to cyber security that were presented in connection with workshop 1 (3) are reproduced in table 1, which lists the risk factors that need to be assessed as a security threat.

Barriers identified at the first MARS workshop 31.01.23:
Auto-speed: System openness; Jamming; Can the navigator overrule the system; External threats, system takeover.
Auto-lookout: System jamming.
Auto-dock: Open or closed system (IT/OT)
Full autonomy: GPS failure; System jamming; Closed or open system, how are cyber threats remedied.

Table 1 Table 1 Barriers identified at Workshop 1, January 31, 2023

This chapter is based on these barriers as well as the existing threat assessment. The aim is to identify the obstacles that exist for the systems addressed in the report and to explore known measures that can reduce the risk of cyber-attacks or mitigate the effects of such an attack.

2 Threat Assessment of Cyber and Information Security

In connection with the defense agreement 2018-2023, there was an increased focus on strengthening the Danish defense against cyber threats. Maritime transport was, in this context, identified as a critical societal sector for which cyber- and information security is of particular importance. As a result, the 'Strategy for Maritime Sector's Cyber and Information Security 2019-2023' was published. The strategy defines information security as a concept that encompasses "*the overall measures to ensure information in relation to confidentiality, integrity (modification of data), and availability. This work includes, among other things, organizing security work, influencing behavior, data processing processes, supplier management, and technical security measures"(4),* while the term cyber security covers the "*protection against security breaches resulting from attacks on data or systems via a connection to an external network or system*"(5). Thus, cyber security focuses on vulnerabilities in the interconnection between systems, including connections to the internet. Both cyber and information security are essential when onboard systems are increasingly automated, especially when the system uses network and information services. The strategy is based on the Center for Cyber Security (CFCS) threat assessment, but it should be emphasized that it is based on a threat assessment from May 2018, and the specific one for the maritime sector is from March 2017. (6) The latest threat assessment is from June 2022 (7), and a review of this shows that it paints a picture similar to that from 2018. The threat from cybercrime and cyber espionage is assessed as high, while the threat of destructive cyber-attacks is assessed as low, in the 2018 assessment on which the strategy is based as well as in the latest from 2022. However, it should be noted that there is an indirect increased risk of destructive cyber-attacks, as CFCS notes that maritime equipment suppliers are particularly vulnerable to cyber espionage, and it is assessed that hackers can potentially exploit compromised equipment suppliers as steppingstones to carry out destructive cyber-attacks on operational systems on ships. For example, attacks can be disguised as legitimate system updates.

In April 2020, the CFCS released a threat assessment of the cyber threat to ships' operational systems, assessing the overall threat from cyber-attacks on Danish ships' operational systems as high. The risk can, in principle, be divided into two: the risk that the onboard system becomes infected and the risk that the system receives flawed signals. The former can, for instance, occur as part of a larger attack across sectors where the ship is not specifically the target of the attack, but where connected administrative networks are compromised, thereby affecting the ship. For example, there have been cases where ransomware attacks have spread from external computers that have accessed the ship's operational system, thereby weakening or completely shutting down the system. Another example is that onboard systems are inadvertently infected, for instance during updates, via USB connection. The CFCS describes in their 2020 threat assessment three attack routes to ships' operational systems: directly via the internet or USB ports, via the ship's administrative systems, or suppliers. See figure 1 which illustrates the attack routes.

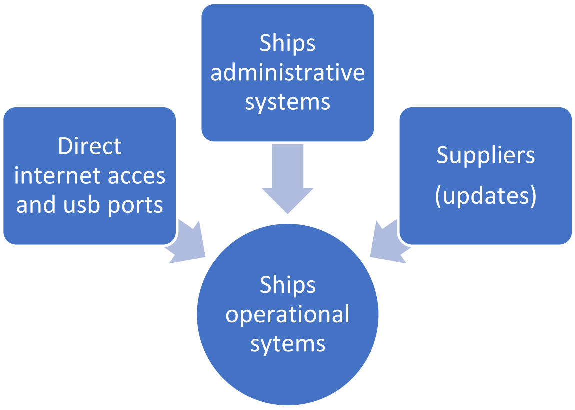

Figure 1 Attack routes to ships' operational systems (CFCS Cyber Threat to Ships' Operational Systems 2020)

The second part concerns the disruption of GNSS signals. GPS is an example of one of these signals, which is essential for the ship's positioning and thus navigation. The signal can either be jammed, where noise signals are sent out that drown out the legitimate signals, or through spoofing, where alternative signals are sent out, e.g. changing the position.

2.1 Described Risks

In the "Strategy for the Maritime Sector's Cyber and Information Security", 3 risks are identified that need to be managed for all ships:

1. Lack of timely response to technical vulnerabilities
2. Lack of process for upgrades
3. Securing critical systems

Ad.1 According to the strategy, in relation to what is observed for land-based systems, there is a technology gap between information technologies (IT - e.g., administrative systems) and operational technologies (OT - e.g., propulsion). A lack of focus on risks and system updates makes both IT and OT systems on ships more vulnerable to cyber-attacks. This vulnerability was emphasized at workshop 1; as an issue that was important to address to increase reliability and robustness in the system. This was again called for attention to at a workshop on cybersecurity for maritime companies.(8) It is thus an important issue to consider when approving a new system, especially when it is to work with existing systems.

In the case of retrofitting, for the three systems; auto-speed; auto-lookout; and auto-dock, the systems will depend on input from already existing systems, primarily OT systems. In this case, there will initially be a technology gap between the existing and the new systems. Therefore, it is important to prepare a risk analysis and ensure updates of existing systems. In the case of the fully autonomous ship, however, the systems are expected to be integrated from the start, and it is important to ensure that over the years a gap between IT and OT systems does not arise and that the systems are continuously updated.

Ad. 2. OT equipment is often updated by the crew, as shown in Figure 1, updating is an action where there is an increased risk of cyber-attacks. At the same time, it is noted that there is a risk of failed system upgrades.

As stated in relation to point 1, a patchwork system will consist of many smaller systems that need to be integrated and each of which needs to be updated. It is important to reduce the risk of attacks or system vulnerabilities that OT equipment updates are planned and systematized as known from planned and condition-based maintenance in general onboard. Although the fully automated ship is assumed to have integrated systems and that without a crew there will be professional updates, it will also be necessary to develop a maintenance plan.

Ad.3 Databases or registers based on old technology are especially vulnerable. Attacks would therefore mean that data could be lost or compromised. This is not directly an issue in the selected case examples, but it should be noted that particularly critical systems should be identified, and their resilience assessed.

3 Guidelines on Maritime Cyber Risk Management

In IMO it has been recognized that there is the need for action concerning the risks associated with ships being more exposed to cyber-attacks when onboard systems move from being isolated units to being connected via internet connections. The IMO's Maritime Safety Committee (MSC) and the Facilitation Committee (FAL) have approved guidance for maritime cyber risk management. The guidance highlights the dangers and risks associated with cyber technology. It is not a detailed guide; instead, it refers to the requirements of the flag state, as well as to guidelines and standards formulated by interest organizations, including IACS Recommendations on cyber resilience; The Guidelines on Cyber Security Onboard Ships, which is prepared and supported by ICS, IUMI, BIMCO, OCIMF, INTERTANCO, INTERCARGO, InterManager, WSC, and SYBAss; and the ISO/IEC 27001 standard.(9)

According to the guideline, section 3.1, the term cyber risk management covers a process where one first identifies, analyzes, assesses, and communicates a cyber-related risk. Depending on this process, one will either accept, avoid, transfer, or mitigate it, so that the risk level becomes acceptable.

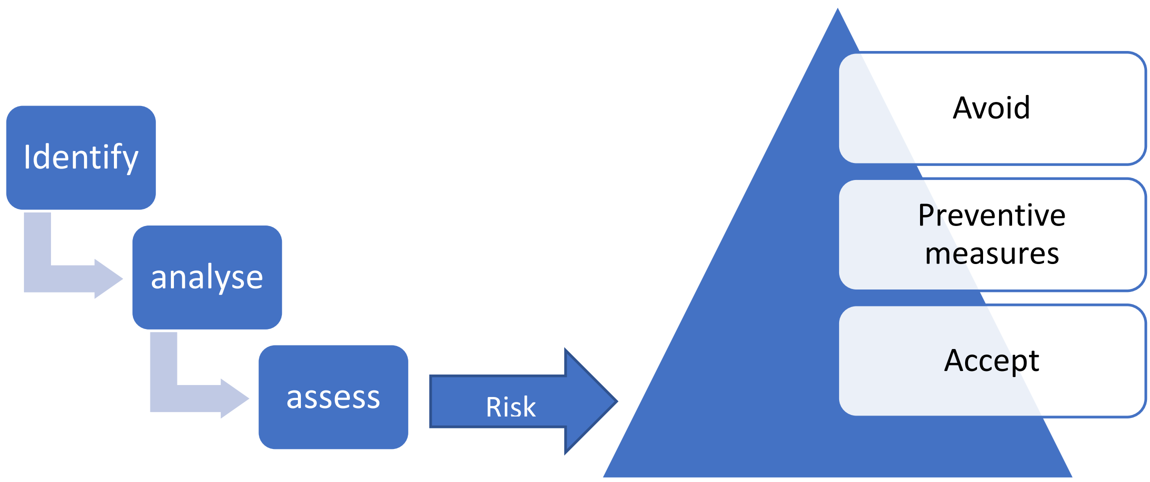

Figure 1 Cyber-risk management

The system resembles the system known from the ISM code(10) and other risk management systems(11).

3.1 IACS Recommendations on Cyber Resilience

From January 1, 2024, it will become mandatory for ships classed by an IACS (12) member, thus all Danish flagged vessel, to develop and implement a cyber-risk-management system. The system is based on a 5-step system, like what is described in the IMO guidance. Table 2 is from IACS URE26 :

1. Identify: Develop an organizational understanding to manage cybersecurity risk to onboard systems, people, assets, data, and capabilities.
2. Protect: Develop and implement appropriate safeguards to protect the ship against cyber incidents and maximize continuity of shipping operations.
3. Detect: Develop and implement appropriate measures to detect and identify the occurrence of a cyber incident onboard.
4. Respond: Develop and implement appropriate measures and activities to take action regarding a detected cyber incident onboard.
5. Recover: Develop and implement appropriate measures and activities to restore any capabilities or services necessary for shipping operations that were impaired due to a cyber incident

Table 2 IACS UR E 26 sektion 3.2. Sub-goals per functional element

From the IACS side, there's a focus on increasing resilience against cyber-attacks. This is done by identifying vulnerabilities in systems, who has access (both individuals and other systems) and ensuring protection as much as possible. It also involves designing a management system to collect and report incidents, so that a database can be established to support future identification of incidents and knowledge of how to quickly return to normal operation. The procedure is also known from accident prevention where near-miss reports increase awareness and avoidance of accidents.

IACS UR E27 relates to cyber resilience for systems and equipment on board the ship. Section 4 contains a list of information that the classification company needs to access concerning computer-based systems (CBS) to be installed on board. This applies whether it's a conventional ship IMO MASS 1 or a ship with an increased autonomy level. The information includes data about equipment (hardware and software) that are part of systems, how they communicate, but also plans for maintenance, testing, and recovery.

IACS's approach to cybersecurity is that one should protect oneself as best as possible against attacks, but that it must be accepted that it can (or even will) happen at some point in time. Therefore, it's important to have thought-through scenarios and to develop contingency plans, as again it is known from the ISM code.

4 Spoofing and Jamming

IACS sets guidelines to establish a management system that addresses the risk associated with CBS. As described in the section on CFCS threat assessment, it's also necessary to assess the risk associated with the disruption of Global Navigation Satellite Systems (GNSS).

IMO has developed a performance standard for *multi-system shipborne radio navigation receivers(13).* Based on the performance standard, the International Electrotechnical Commission (IEC) has developed specifications for testing. Equipment that meets these specifications will sound an alarm in case of an error, so the navigator is informed and can take the necessary precautions. The performance standard is considered a recommendation, but especially in connection with a MASS 3 ship, as treated as a case here, it is expected to be considered a requirement. The challenge in connection with retrofitting is that the existing equipment does not necessarily meet the performance standard.

INTERTANKO has developed a guide for the navigator (14) with recommendations for actions that can detect irregularities in GNSS. These can be used onboard by the navigator on MASS 1 and 2 ships, and by the operator on a MASS 3 ship. However, it must be assumed that there is a risk that the signal between ship and land can also be affected, so the operator, despite control actions, may not necessarily detect disturbances. An onboard navigator in coastal waters can use terrestrial navigation as a basis for comparison. This will not be possible to the same extent for an operator on land if the signals are disturbed.

It is recommended to develop a contingency plan for the navigator/operator to follow if jamming or spoofing is detected. It describes what immediate actions should be taken onboard/on land and what should happen when the situation stabilizes. It must be emphasized that it is essential to train these on a regular basis.

There is currently no regulation that sets requirements for resilience against jamming or spoofing, but based on guidelines from IMO and INTERTANKO, the following can be recommended to reduce risk and thereby document to the approving authority that it has been considered:

1. MSC. 1/Circ. 1575 Guidelines for Shipborne Position, Navigation, and Timing (PNT) Data processing are taken into consideration. A newly built MASS 3 ship is recommended to follow the circular. For retrofitting on MASS 1 and 2 ships, existing equipment is mapped, and dependence on GNSS signal is investigated and documented.
    a. Testing of detection can be carried out in a simulator or protected test area.
2. Contingency plan is prepared. Action depends on the ship type. For example, if a MASS 3 detects jamming of the signal, how should it proceed?
    a. Testing of action can be carried out in a simulator or protected test area.
3. A plan for education and training of jamming or spoofing situations should be prepared.

5 Finishing Remarks

Cybersecurity is a significant challenge for the shipping industry, as it is for several other sectors. As ships become more connected to the mainland via networks, the risk of attacks increases, as this provides access to systems that, for many ships, are as old as the ship itself and are either not updated or cannot be updated to the current security level.

This means that even though cybersecurity was considered a major barrier in both workshops, the issue is not unique to MASS ships. It's a problem that all ships, regardless of age and type, must address. The nature of the problem and how it should be tackled is unique from ship to ship. However, it must be a crucial part of an approval process, which also means that a system that is to be retrofitted onboard a vessel must be approved for that specific vessel. Hence the integration with existing equipment that can pose a safety risk. Meanwhile, for a fully autonomous ship, it is assumed that integration is part of the design and construction phase. The question then becomes, what if the ship is subjected to an attack and there is no human in the loop, how does the ship 'react'? This is important to describe as part of the ship's cybersecurity management plan and as a part of the contingency plans (fallback state within as well as outside of the operational envelope). It will also be essential to test and be able to test how the system is affected by cyber-attacks. This will mean that onboard exercises can be conducted, like what is known from man-overboard and, most recently, pirate attacks, which can train the crew and/or land operators to handle these situations.

Chapter 4

Society's Readiness for Autonomous Shipping

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Colophon

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Learn more here: https://nextgenrobotics.dk/maritime-autonomous-reliable-systems/.
The authors of the report are solely responsible for its content.

Introduction: Society's Readiness for Autonomous Shipping

Autonomous vessels, drones, robots, and cars are rapidly emerging as technology matures and society's readiness increases. The visions for these technologies are vast, and they are assumed to have a significant impact on the future structure of society. It is evident that the receptiveness of society, and thus the authorities, the public sector (municipalities, regions, and other actors), businesses, and citizens to implement these technologies is crucial for their success. This chapter uncovers the existing knowledge about societal readiness for autonomous ships. Societal readiness refers to society's receptiveness to a new technology and readiness to accept this technology's use in the public domain. Thus, we can discuss society's readiness to accept technology, where readiness can be continuously influenced and changed – both positively and negatively.

The assessment of society's overall reaction is a collective evaluation of individual stakeholders' readiness and the overall societal interests. This involves both direct stakeholders, such as employees and consumers, and stakeholders affected more indirectly, like the general population.

Society's readiness regarding the application of new innovative technologies can significantly influence the possibilities for their commercialization, especially when implemented in the public domain. To understand the commercialization of autonomous ships, it's essential to have a profound understanding of broader societal perspectives on how technology will influence and be perceived by different stakeholders and the wider population.

To uncover society's readiness regarding the implementation of autonomous ships in Denmark, a study of existing research literature is undertaken. Based on this, the existing knowledge is summarized, and a preliminary assessment of readiness for autonomous ships from a societal perspective is made.

There are various ways societal readiness can be defined and delimited in academic literature. Therefore, the literature study will be based on searches for concepts like social readiness, societal readiness, public readiness, public opinion, and the use of online academic search engines like Scopus and Google Scholar. Since autonomous shipping is a relatively new technology, the relevant literature is also of recent origin, and the study identified eight articles published from 2019 to 2022 (see table 1).

Author	Pub. Yr	Title	What they Investigate	How They Investigate	Main Conclusions in Relation to SRL
de Klerk, Manuel, & Kitada	2021	Scenario planning for an autonomous future: A comparative analysis of national preparedness of selected countries	National perceptions of societal readiness and maritime policy, legislative frameworks, and human resource development to carry out autonomous ship operations in selected countries (Norway, Singapore, the Philippines, South Africa).	Literature review, survey, and interviews.	The study leads to the identification of four scenarios for future use of MASS. Scenario 1 (2020): Business as usual; autonomous vessels operate with crew on board and only in domestic waters. Scenario 2 (2025): Reduced manning on conventional ships and first fully autonomous ships in operation without crew on board, in domestic waters. Scenario 3 (2035): Autonomous ships operate in domestic waters without crew on board. Scenario 4 (2040): Fully autonomous ships operate in international waters without crew on board. The study does not directly investigate societal readiness but concludes that increased collaboration with stakeholders such as industry, universities, and public decision-makers, e.g., politicians, is necessary to achieve the necessary readiness in society.

Goerlandt & Pulsifer	2022	An exploratory investigation of public perceptions towards autonomous urban ferries	Public perception of autonomous urban ferries	Through telephone surveys and interviews, public attitudes towards a hypothetical autonomous urban ferry in Halifax, Nova Scotia are investigated. The focus is on safety perceptions of different levels of automation	Safety is the main issue. The ferries are perceived as being unsafe.
Li & Yuen	2021	Autonomous ships: A study of critical success factors	Critical success factors for autonomous shipping	Literature study	Stakeholders are important. The most important types are: Employees Shippers Legislators Shareholders Insurance companies
Mallam, Nazir & Sharma	2019	The human element in future Maritime	The study examines the potential effects of autonomous technologies on future work	Ten subject experts, working within the industry and academia, were interviewed to get	Four main themes were identified: (i) trust, (ii) awareness and understanding, (iii) control, (iv) education and work organization. A fifth more unclear theme regarding practical implementation considerations was also found. This includes various sub-topics related to the

		Operations – perceived impact of autonomous shipping	organization and roles for people within maritime operations	their perspectives on the current state and future implications of autonomous technologies	implementation of autonomous ships in the real world.
Porathe	2021	Autonomous Ships: A research strategy for Human Factors research in autonomous shipping	The article argues that the interaction between human and technology is crucial for success with MASS. Automation is assumed to increase the safety and efficiency of the technology while it can reduce costs and accidents. "Human-automation interaction, as it can manifest between operators and the human-machine interface in the Remote Operation Center (ROC), between	Based on existing literature and studies, eight future research tasks are identified	The eight research tasks are: Simplification of the traffic environment, increased predictability of ship traffic, situational awareness in remote monitoring, Quickly-Getting-Into-the-Loop Display (QGILD), remote operator - Bridge Interface (ROBIN), automation transparency, human intervention and handover, Interaction with conventional ships at sea. Especially relevant for this study is the importance of Operator Readiness Level (ORL), which is directly linked to human interaction with the technology.

			autonomous and conventional ships at sea, and between crews on partially manned ships and automation”		
Theotokatos, Dantas, Polychroniди, Rentifi og Colella	2023	Autonomous shipping — an analysis of the maritime stakeholder perspectives	The study aims to investigate the current understanding and perspectives on the maritime industry as they emerge from different stakeholders. The focus is on challenges and requirements for design and implementation	Two survey studies are used, where the first is shared with a broad set of stakeholders and survey two is shared solely with stakeholders familiar with the industry	There is general agreement among respondents that autonomous shipping will bring (at least) some benefits to the industry. The study finds that investment costs will be the biggest challenge. The need for regulation also finds great support and finally, the study finds that the importance of education and qualified labor is of great importance

Veitch & Alsos	2021	Human-Centered Explainable Artificial Intelligence for Marine Autonomous Surface Vehicles	Can a human-centered approach to XAI contribute to building trust among the real-world ASV users?	In this article, the researchers constructed the concept of 'human centered' XAI to meet the distinct needs for end-user interactions for ASVs/MASS	The results showed that the main objectives of human centered XAI processes were to improve (1) usability, (2) trust, and (3) safety. Usability was improved through representation of AI functionality; trust was strengthened through representation of AI decision making, sensory perception, and behavior; and safety was improved through representation of AI limitations and human-AI collaboration. All representations were enabled by interconnected processes of analogy making, visualization, and mental simulation, seeking to align AI goals and actions with the values that end users have when interacting with ASVs.
Wiśnicki, Wagner & Wołejsza	2021	Critical areas for successful adoption of technological innovations in sea shipping – The autonomous ship case study	Investigates the key factors contributing to successful application of technological innovation in shipping. The focus is on three critical areas: technological readiness, social readiness, and technological implementation process.	Patent data, survey, interviews, and R&D projects are used.	The shipping industry is falling behind compared to other industries in developing and implementing new technologies and relies primarily on technologies that are tested and used in other market segments. The social groups most affected by the implementation of innovative technologies are very positive towards them

Innovation Fund's Societal Readiness Level (SRL) Scale

Understanding society's readiness for various new technologies can be challenging based on a qualitative description. To provide a more structured overview, we will preliminarily categorize society's readiness using the Innovation Fund's scale for Societal Readiness Level. The Innovation Fund classifies SRL into nine distinct levels (Table 2), ranging from: *SRL 1 - Identifying the problem and gauging societal readiness*, to *SRL 9 - Demonstrating actual project solutions in a relevant environment* (Innovation Fund Denmark, 2019).

Levels
SRL 1 – Identifying problem and identifying societal readiness
SRL 2 – Formulation of problem, proposed solution(s) and potential impact, expected societal readiness; identifying relevant stakeholders for the project.
SRL 3 – Initial testing of proposed solution(s) together with relevant stakeholders
SRL 4 – Problem validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness
SRL 5 – Proposed solution(s) validated, now by relevant stakeholders in the area
SRL 6 – Solution(s) demonstrated in relevant environment and in co-operation with relevant stakeholders to gain initial feedback on potential impact
SRL 7 – Refinement of project and/or solution and, if needed, retesting in relevant environment with relevant stakeholders
SRL 8 – Proposed solution(s) as well as a plan for societal adaptation complete and qualified
SRL 9 – Actual project solution(s) proven in relevant environment

Results of the study

Many countries have not yet addressed the specific theme of readiness for autonomous ships in the future. A study suggests that the main reasons are either a lack of attention to the subject or that other policy areas have more immediate focus (de Klerk, Manuel, and Kitada, 2021).

The implementation of autonomous shipping is still at a relatively early stage, and the research focus remains primarily on technological development, demonstrating technological feasibility, and the legislative framework. In contrast, the focus on implementation challenges, especially those concerning societal readiness, is limited (Wiśnicki, Wagner, and Wołejsza, 2021). As the technologies are still under development and at low TRL levels, their application also remains at a low level (see scenarios in de Klerk, Manuel, and Kitada, 2021). Thus, there is limited testing of autonomous ship functions at low autonomy levels (see cases in chapter 1).

Upon reviewing the literature, we found that existing literature remains primarily conceptual with very limited empirical data from actual experiences with autonomous ships. **Based on the conducted literature study, it is assessed that SRL is currently met at level 2, and current efforts are aimed at level 3**. Level 2 corresponds to completed "formulation of problem, proposed solution(s), and potential impact; expected societal readiness; *identify relevant stakeholders for the project*" (Innovation Fund Denmark, 2019).

Efforts to raise SRL to level 3 require *initial testing of proposed solutions with relevant stakeholders*. There are very few examples of what can be termed "*initial testing*", and there is still a need for more testing of possible solutions before SRL 3 can be said to have been reached.
In the specific case of the MARS project, the selected cases aim to ensure the possibility of evaluating different forms of autonomy and involving users, e.g., staff. These efforts can support a higher SRL level.
The results from the various studies can be divided into three categories. An overview of the approach and results from the different studies used can be seen in table 1.

Stakeholders

The study by de Klerk, Manuel, and Kitada (2021) does not directly examine societal readiness but concludes that increased collaboration with stakeholders such as industry, universities, and public decision-makers, e.g., politicians, is necessary to achieve the necessary readiness in society. Yuen and Fai (2021), on the other hand, directly identify the stakeholders expected to be important for the successful implementation of autonomous ships, employees, shippers, legislators, shareholders, and insurance companies. They expect that many of these actors will be critical of autonomous ships.

The authors conclude that it is essential to be aware of and further investigate how these actors' attitudes and experiences with autonomous ships will evolve when they come into contact with the technology. Overall, there is no firsthand knowledge about stakeholders' interaction with autonomous ships, and as this will be crucial for future integration of autonomous ships, it is recommended that knowledge is obtained as prototype projects and trial voyages are launched.

Public Perception

Goerlandt and Pulsifer (2022) have examined the public's perception of autonomous urban ferries. Here they find that autonomous urban ferries are perceived as being unsafe and that safety is the biggest issue among the surveyed population. This study is based on a hypothetical ferry, so no conclusions can be drawn from actual experiences with autonomous ships. Therefore, further research on specific tests of autonomous ships will be needed to increase familiarity and get realistic reactions to the technology. However, the result indicates the importance of working on solutions that make people feel safe and secure with autonomous ships. Both Vetich and Alsos (2021) and Mallam, Nazir, and Sharma (2020) look into how human interaction with autonomous ships can be designed, which can help enhance a sense of safety.

Human Interaction with Autonomous Ships

Vetich and Alsos (2021) argue that there is a need for what they call human-centered 'Explainable artificial intelligence (XAI)' to address the specific needs of end-user interactions with autonomous ships, as this can help improve usability, trust, and safety. Based on the latest research, they use analogy, visualization, and mental simulations to improve introductions to the new concepts associated with autonomous ships.

Mallam, Nazir, and Sharma (2020) have, through expert interviews, investigated the potential impacts of autonomous technologies on future work organization and roles for humans within maritime operations. Four main themes emerged: (i) trust, (ii) awareness and understanding, (iii) control, (iv) education and work organization. Likewise, Wiśnicki, Wagner, and Wołejsza (2021) examined both future employees (namely students in training) and users of ferry services' attitudes towards autonomous shipping. For employees, the survey finds that the majority of the navigation students surveyed are ready to incorporate new technological solutions and challenge their current and future tasks related to autonomous ferries. Theotokatos et al (2022) examined several stakeholders' perspectives on the transition from traditional to autonomous shipping. In general, the study finds that all groupings, although they view the transition differently, are positive about the potential benefits to the industry. However, seafarers are more skeptical across various questions, and it's worth noting that there is strong agreement on the importance of relevant education with the implementation of new technology. This study also confirms the importance of knowledge and experience with technology and how positive respondents are towards the technology. Therefore, experiments with and implementation of autonomous technology will require the involvement of all relevant close stakeholders. The study also finds that all groupings prioritize the following areas as most suitable for the implementation of autonomous technology: coastal areas, short routes, and ocean-going ships, and find that cruise ships are the least suitable.

Few studies have investigated (future) users' attitudes towards autonomous ferries. Wiśnicki, Wagner, and Wołejsza (2021) conducted a survey of customers on the ferry between Świnoujście (Poland) and Ystad, Trelleborg (Sweden). The study found, among other things, that 26% believe that autonomous ships will be more trustworthy than traditional manned ships, as IT systems have an advantage over humans. In total, 85% of respondents believe that autonomous ships are as good or on the same level as traditional ships. However, there is also a relatively large proportion of 30% who have not yet formed an opinion about autonomous ferries. 37% of respondents are ready to use autonomous ships on the route as soon as it becomes available. An additional 37% will base their decision on feedback from someone who has already tried such a ferry and is positive about it. Only 7% of respondents are not interested in using autonomous ferries for transportation.

In conclusion, they identify the concerns that consumers will have about the use of autonomous ferries (figure 1). The figure shows that safety is the biggest concern (34% of those surveyed). At the same time, it is also clear that it is not something that citizens have thought about since 29% answer "do not know".

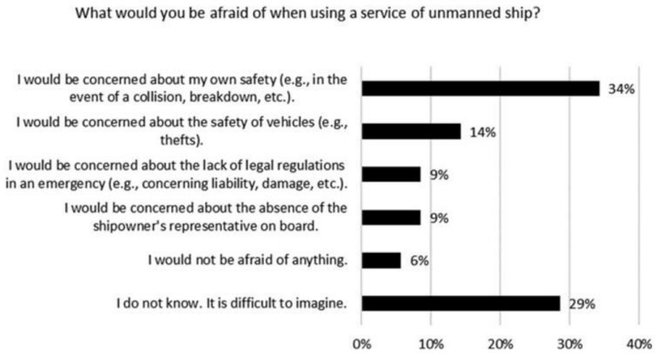

Figure 1: Worries about the use of an autonomous ferry (from Wiśnicki, Wagner og Wołejsza, 2021: figure 8)

Future Needs: Test Area and Follow-up Research

To raise societal readiness to level 3 and later 4, the proposed solutions and impacts found in previous tests must be validated through specific pilot tests and user tests in relevant environments. Several countries like Norway and soon Denmark are designating test areas, which could prove to be an essential tool. Initially, the focus will be on validating the proposed technical solutions and conducting preliminary tests of autonomous ships.

The literature argues for a more nuanced understanding of readiness, which complements technological readiness (TRL) with market readiness (Market Readiness Level), regulatory readiness (Regulatory Readiness Level), and organizational readiness (Organizational Readiness Level) (Vik, Melås et al., 2021). Combined, these will constitute a comprehensive assessment of a technology's possible application horizon. However, it is beyond the scope of this chapter to gain the necessary insight and associated data foundation to make a comprehensive assessment of Denmark's readiness for autonomous ships across these types of readiness. We refer to the need for further research in the field, building on studies like those by de Klerk, Manuel, and Kitada (2021).

When establishing a test area, politicians can advantageously set up a follow-up group that can engage in ongoing dialogue with close stakeholders such as citizens and municipalities. Simultaneously, there should be a specific focus on follow-up research linking technological development with the mentioned systemic factors and readiness levels. Previous research in the drone area has shown that citizens closely associated with testing new technology achieve a higher level of familiarity, which can be positive (e.g., when they understand the benefits of the technology) but also negative (e.g., because of the space in the local environment that technology occupies). Citizens' perceptions of the technology will ultimately also affect the societal readiness level (Fasterholdt et al. 2023). Setting up follow-up research can provide the precise knowledge needed to design solution proposals based on the local users and stakeholders' attitudes and experiences with autonomous ships, ensuring the best starting point for the successful implementation of the technology in Danish waters.

A Look into the Future - Linking Autonomous Technologies on Land, Water, and Air (1)

It is evident that societal expectations for widespread adoption depend on integration with other autonomous technologies such as drones, self-driving trucks, and autonomous systems in general. Currently, society has the most experience with self-driving cars, and the literature is significantly more comprehensive. Autonomous ships are expected to be part of a larger autonomous logistics system, linking autonomous subsystems focusing on self-driving trucks (2), air transport, and ships, and later integrating drones in non-segregated airspace (3). This report highlights the need for more knowledge about the opportunities and barriers to integrating various autonomous systems to realize all the potential for using autonomous technology in Denmark. To illustrate this knowledge gap, it's evident that legislation cannot focus solely on individual technologies but should adopt a systemic perspective across autonomous technologies, whether on water, in the air, or on land. Given this chapter's focus on societal readiness, it's clear that citizens will view the technologies in context and not necessarily distinguish between technology types. Thus, all autonomous technologies will have to meet standards for safety and integration into society's other known functions.

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Chapter 5

Technical Maintenance of Equipment on Autonomous Ships

By Søren Nyborg Hansen, SIMAC (snh@simac.dk)

1 Introduction and Limitation

Maintenance, as also described in sub-report 2 on risk assessment, is an essential element to achieve a desired safety level. It is crucial to develop a plan for how a system should be maintained in addition to a risk assessment, both in terms of the type of maintenance and who should oversee it. The choice of maintenance model will depend on the specific system, so it is not possible to specifically describe a maintenance model in this report.

This sub-report will not discuss the maintenance of the propulsion system, as it is expected to be previously described, as it is assumed to be the same installation as in any other ship of the same type. However, reference can be made to Stig Eriksen's Ph.D. thesis from 2021 "*Autonomous Ships from the Perspective of Operation and Maintenance*".

The sub-report will instead provide an example of maintenance of equipment related to "Autonomous" ship operations and the competency requirements for the person responsible for the maintenance. The auto-lookout is chosen as an example since it is known from the industry, and therefore concrete knowledge can be included.

2 Auto-Lookout

Equipment to assist the navigator in lookout requires daily supervision and maintenance, as these systems are presumed to be based on optical systems containing lenses. In a maritime environment, the performance of these systems will quickly decline due to lens contamination, requiring supervision before reliable performance can be expected.

Especially when using Lidar systems (Light Detection and Ranging), which are widely used in the industry to guide self-driving robots but contain systems sensitive to contamination.

Therefore, regular inspection, cleaning, and calibration are necessary to ensure the system works correctly and accurately.

Here are some essential steps that can be part of the maintenance process:

Inspection: Examine the system for any visible damage or defects. Check cables, connectors, and mechanical parts to ensure they are in good condition.

Cleaning: Clean the lenses and mirrors in the Lidar system to remove dust, dirt, or spots that may affect performance.

Calibration: Lidar systems may require periodic calibration to ensure accurate measurement. This typically involves the use of calibration targets with known distances or reflectivity to verify and adjust system performance.

Firmware and Software Update: Keep firmware and software updated according to the manufacturer's recommendations. This may include downloading and installing updates or patches to enhance functionality and fix known issues.

Testing and Validation: Perform regular tests and validation procedures to ensure the Lidar system works correctly. This may involve performing measurements in known environments or comparing results with other reference instruments.

Documentation and Logging: Keep track of maintenance activities and log any problems or changes in system performance. This helps identify patterns or potential issues and facilitates any future troubleshooting.

It's crucial for the system's reliability that it's maintained by qualified personnel. Therefore, continuing education is recommended.

To maintain Lidar systems, it's useful to have an educational background in electronics, optics, and measurement technology. Below are some relevant educational areas and courses that can help build the necessary knowledge and skills:

Electronics: A basic understanding of electronics is crucial as Lidar systems contain electronic components and circuits. Knowledge of electronic theory, circuit design, troubleshooting, and repair will be beneficial.
Optics: Since Lidar systems use laser light and optical components, knowledge of optics is essential. This includes understanding light waves, reflection, refraction, lenses, and mirrors.
Measurement Technology: Measurement technology and precision measurements are central to Lidar systems. An education in this area will cover the principles of measurements, calibration, accuracy, uncertainty, and instrumentation.
Laser Physics: A basic understanding of laser physics is useful for handling and understanding the technical aspects of Lidar systems. This includes laser operation, laser properties, and safety procedures.
Data Analysis and Signal Processing: Lidar systems generate vast amounts of data that need to be analyzed and processed. Knowledge of signal processing, image processing, and data analysis will be beneficial for properly utilizing and interpreting Lidar data.
Maintenance and Troubleshooting: A general education in maintenance technology and troubleshooting will help develop the necessary skills to diagnose and fix errors in Lidar systems. This includes troubleshooting hardware, software, and electronic components.
Manufacturer Certifications: Many Lidar system manufacturers offer specialized training courses and certification programs. These programs can provide in-depth knowledge of specific systems and their maintenance and document one's expertise.
It's essential to note that the specific educational path may vary depending on the type and application of Lidar systems. It's recommended to investigate the requirements and recommendations specified by manufacturers and consult professionals in the field for detailed guidance on relevant education and training.

There will likely also be other optical systems, such as night vision cameras and FLIR cameras (Forward-Looking Infrared), which is an advanced thermal camera that uses infrared imaging

technology to capture heat radiation and produce thermal images. Maintaining a FLIR camera is crucial to ensure reliable performance and accurate thermal measurements.
Maintenance of night vision and FLIR cameras is almost identical to maintaining the LIDAR system and will therefore not be further described.
Autonomous systems will require a deeper knowledge of computer system maintenance and updating their system software and firmware.
Daily inspections and maintenance can be performed by daily checking the system components and their condition without disassembling components. This can be done by the operator if they have completed the necessary additional training in the ship's equipment package.

Further training of the ship's staff for the maintenance of "Autonomous" systems becomes a necessity to achieve the necessary reliability of these systems. It will be a requirement for a greater understanding of complex and integrated systems with many different sensors, all of which must be able to communicate with central computer systems. Therefore, sensor technology and how the individual components work and are maintained are necessary for the maintenance staff.

In addition, topics such as cyber security must be strongly considered, as it will pose a significant threat to system reliability. This threat grows with the proliferation of systems and becomes a threat to all shipping, which must be protected against. Here, continuing education is also a necessity to achieve reliable operation of the systems. Therefore, future navigators and engineers will need to have more knowledge about security and protection of critical systems against cyber-attacks.

Chapter 6

Skills and Education, Curriculum Changes

Primary Author Mie Jensen (amj@marnav.dk)

1 Introduction

Marstal Navigation School facilitated a workshop on May 10, 2023, focusing on the need for possible changes in the curriculum of educations due to the rapid development in autonomy in the maritime industry.

The workshop program was prepared by Kresten Petersen and covered the following topics:

- Presentation of the current educations
  - Bachelor in Maritime Transport and Nautical Science, SIMAC
  - Bachelor in Technology Management and Marine Engineering, SIMAC
  - Ship Master, Marstal Navigation School
- What are the challenges in relation to education and autonomy
  - Focus on the Master Mariner Education
  - Focus on the Marine Engineer Education
- Drone Operator Education

Participants SIMAC: Charlotte K. Flugt, Signe Jensen, Jesper Kollerup, Mads Monrad, Mette Bennedsen and Katja Feltman.
Participants Marstal Navigationsskole: Kresten Petersen, Henrik Steen, Henrik Hagbarth Mikkelsen and Mie Jensen.

2 The Robot as a Colleague

Aarhus University released a report titled ROBOTTEN/TEKNOLOGIEN SOM "KOLLEGA" (1) in 2020. It is a result of a project with the aim to "*create new knowledge about how the relationship between humans and automated technologies develops and changes when they become 'colleagues', and consequently provide recommendations on which new non-technical skills and working methods need to be developed in the shipping industry when the nearest colleague is a robot, drone or other automated technology."*(2)

One of the discussions in relation to skills is the need for onboard experience and level of education for the operators who will handle test vessels and eventually also Remote-Control Centers. It is noteworthy that the report states:

"*Our investigation points out that developers without sailing experience and with a lack of opportunity for access to the vessels may come to underestimate the complexity of the work processes on board and the competence and experience they require. For example, one developer described how he believed that harbor maneuvers, where the ship docks, are primarily based on guesswork, inaccuracies and inadequate data, which he found problematic: 'They guess. If it's Bjarne for example, who says it, then it's 20 meters. It may correspond to 30 meters in reality.' Our observations on board however point out that docking is an activity characterized by high precision, experience and cooperation. It does not mean that data from technology would not be able to contribute – the question is just what data will be useful, and how a potential new technology can be meaningfully integrated into the existing action patterns and tasks.*"(3)

The question of skills thus becomes two-fold. (a) the skills that a crew member on board needs to acquire when the "colleague" becomes digital. (b) the skills that an external (developer, test operator or land-based operator) needs to acquire to understand the environment in which the system will operate.

Crew Member

When interacting on board with a digital colleague, one perspective might be to approach it as we currently do with human colleagues in education. Students are required to attend a course of training in medical care that qualifies them to take charge of medical care onboard. They are not trained medical professionals, but they acquire skills to conduct diagnosis and treatment with support from land. Another aspect is HRM including intercultural understanding. Both subjects could be transferred to a digital colleague, just as the support from land, today radio medical, could be transferred to a land-based support center where crew members are trained to diagnose and perform repairs with remote support.

External

A system developer and a test operator, using the analogy of *the robot* as a colleague, can be compared to a teacher. It is important, as also emphasized in the report, to understand the reality in which the system will operate, the perspective the remaining crew has on the task. This dilemma also arises when an ROC (Remote Operation Center) is to monitor the vessel. As long as manned ships exist, it's necessary for the operator to understand the other crew members' perspective when acting in a critical situation.

In the report regarding the robot as a colleague, it's noted: Critical approach, *system understanding, and the ability to act correctly and quickly when the situation requires, are thus a complex set of skills, which are absolutely crucial for navigation and other critical tasks, and as the examples above show, the need for these skills and the officer's experience and judgement do not become less significant with the introduction of digital technologies - rather the opposite. Technologies can create new dilemmas*. (4) In assessing future skills needs, it's necessary to consider this.

3 Bachelor in Maritime Transport and Nautical Science (Master Mariner) SIMAC

The legal notice on the education to Bachelor in Maritime Transport and Nautical Science sets the framework for the Master Mariner education. It's the education institution that must ensure that the education meets the requirements of the STCW (Standards of Training, Certification, and Watchkeeping) convention. Changes in the existing education are thus possible for the institution to implement as long as this is within the frame set by the notice. This allows the education institution to keep up with the development and adapt to increased levels of autonomy. It should be noted that this is on a national level. Danish educations comply with the STCW convention (6). Changes to an international convention such as STCW will result in a long processing time. Thus, the STCW convention could end up being a limiting factor. However, it's possible at national level to add learning objectives, as STCW only should be seen as a minimum requirement.

Throughout the years, there have been ongoing adjustments to ensure that education corresponds to the reality onboard a vessel. It is important to point out that the education, as it is structured today, aims at generic competencies. Thus, a requirement is that a student should be able to act as a duty officer on a vessel with an integrated bridge system and in principle also on a ship sailing with paper charts and using a sextant for position determination.

To address this, efforts have been made in recent years to continuously adapt the education, and a subject like navigation has undergone several changes from primarily being a tool subject to today placing great emphasis on training in mindset. Students first learn basic skills enabling them to read a chart, find the ship's position, and the rules of the road. In the last semester, the emphasis is now on elements such as Situational Awareness and data understanding. These are topics expected to be important as the level of autonomy on board increases. Within the frame set by the legal notice, it's possible to either offer electives or tune the general content to prepare the students for increased autonomy on board.

4 Bachelor in Technology Management and Marine Engineering (Marine Engineer) SIMAC

The legal notice regarding education for a Bachelor in Technology Management and Marine Engineering (7) sets the framework for the marine engineer education. It is the educational institution that must ensure that the education meets the requirements of the STCW Convention. It's important to note that there are two paths for students; the education is fundamentally organized as a generic engineering education where it is possible to choose the sea package. In combination with sea time, it allows, after graduation, to sail as a marine engineer. The education is thus organized so that the student acquires generic competencies, but with the opportunity to specialize. Just like for the Bachelor of Maritime Transport and Nautical Science, the educational institution can itself implement changes, provided this is within the frame the notice establishes.

It is noted that as the education is organized today, the maritime subjects prevent the students from choosing other electives. This should be considered if competence-giving courses are to be developed and to be included as electives. There are already today electives that strengthen the students for increased automation, including electives like:

- Network in automation solutions
- Robot programming
- Maritime automation and IT PLC and fieldbus

It should also be noted that the marine engineers, as they are educated for both land and sea, are trained in system understanding of highly automated systems as this is part of the general education. According to the study coordinator, the education is organized in close dialogue with the industry so that among other things, the recipients have the opportunity to provide input. At present, there is no expressed desire for an education or a special focus on autonomous ships, but it will be possible to change or adapt to this if the wish arises.

5 Shipmaster Education, Marstal Navigation School

The education to become a shipmaster at Marstal Navigation School is unlike SIMAC not a Bachelor of Professional Studies. However, the progression of the educations is the same. Initially, the basic skills are taught, and then the mindset expected of a navigator is trained, primarily through simulation exercises. Legal notice 363 of 25/06/19 Education for shipmaster, which Marstal Navigation School teaches according to, contains, unlike legal notice 1349 which SIMAC uses, no requirement for teaching in autonomy.

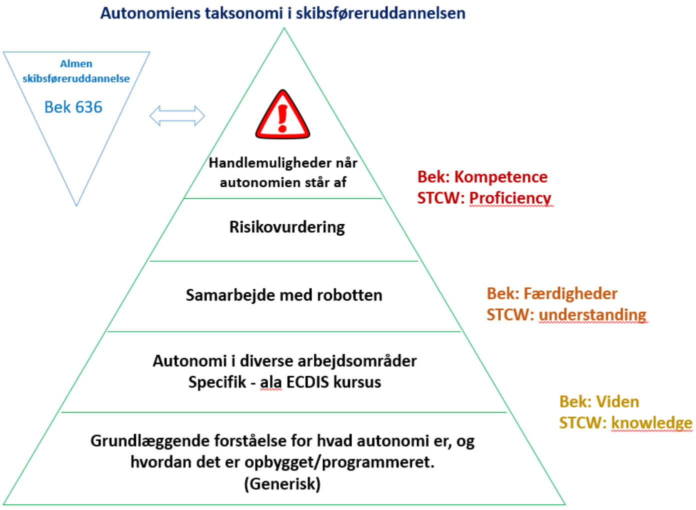

Figure 1 Taxonomy of autonomy in Ship Master education

In the 3rd semester, the institution offers the subject FabLab. The students are taught to program autonomous ships. They must convert the basic skills, previously taught in the education, into programmable processes in the autonomous ships. There is also a focus on the uncertainties that can occur in the electronic systems. The didactic considerations underlying the subject FabLab, give the students a basic understanding of the autonomous processes they will encounter onboard.

If the students' competencies are to meet the requirements to work with autonomy as a colleague, further training in Situational Awareness is needed, as is also done at SIMAC.

A deeper understanding is needed. The students must be able to risk assess the autonomous systems. They must be able to step in when the autonomy fails. To be able to step in when the autonomy fails, the students must know the basic skills, which are also known from the educations as they appear today. But before autonomy fails, the students must be able to analyze their way to it happening, problem-solve, risk assess and then take command in any given situation. Situational Awareness is not to be confused with Full mission courses, there is a need for a separate course with focus, risk assessment and mindset. Which is not part of the current teaching at Marstal Navigation School.

6 Drone Operator

According to the standard of watch-keeping (8) and COLREG (9), the duty officer must be able to navigate the ship safely in all normal and extraordinary situations. According to COLREG rule 8, the officer must be able to take any action to avoid collision, this should be done clearly and distinctly, in good time and in accordance with good seamanship.

Given the high international demands on the watchkeeper, whom the drone operator must be equated with, there should also be greater demands on the education a drone operator must have completed to be able to act in the field.

If the drone operator is not properly equipped to perform the task as a watchkeeper and if the drone operator does not have knowledge and understanding of the maritime world's concept of good seamanship, then the combination of drones and manned ships will pose a significant safety risk. The drone operator's education should therefore be of at least six months' duration. They should be taught navigation at the same competency level as in the coastal skipper education. It can be argued that there is a lesser need for learning about cargo handling. However, there should be more focus on network, digital understanding, and computers. There should be a different focus on maritime law and administration. There should be a new focus on working with remote control, including situational understanding and risk assessment in digital systems.

7 Conclusion

There was broad agreement during the workshop that the development within autonomy in the maritime profession imposes demands on educational institutions. Autonomy will require a change in the future mindset. Students must learn to collaborate with autonomy, and at the same time, they must have the competencies to take over if autonomy fails.

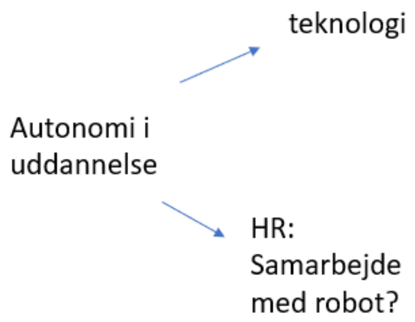

Figure 1 Two roads for autonomy

The institutions agreed that there are two facets, the basic understanding of autonomy technology and the human aspect.

Training in situational awareness will become an important part of the future shipmaster education competency goals.

A difference was seen in the Navigation schools' concern as opposed to the MARS project. Navigation schools were oriented towards long-term goals and saw a clear concern for lack of understanding and exercise of 'good seamanship' among drone operators, if they are not educated shipmasters and have these competencies. Whereas the MARS project has a need for a quickly completed education requirement so that test ships can sail soon.

If drone operators do not operate the ships with the same understanding as the navigators on the manned ships, it could cause misunderstandings at sea, thereby posing a significant safety risk.

References for MARS report

"A framework for understanding the barriers when sailing autonomously"

Framework:

1 Blanke et al (2017) s. 14

2 The information is based on the article "Første førerløse danske færge kan være en realitet in 2023" in Maritime Direct from 1/11 2022 as well as on information from the website of Shipping lab www.shippinglab.dk

3 https://cordis.europa.eu/project/id/314286 (05062023)

4 The authors of this report have noted that there has been equal vessel designed and build as in the written scenario. Here we do not look at an existing scenario, therefore it should bed noted that it covers a non-existing scenario.

5 Grant agreement number 636027

6 H2020 Research and Innovation (MG 4.1-2014: Towards the energy efficient and emission free vessel)

7 https://shippinglab.dk/work-package-2-autonomy/ (Hentet 09/01/2023)

8 The Green Hopper projektet under Shipping Lab covers exactly this.

9 Sea Machines is a company engaged in highly autonomus maritime systems, see https://seamachines.com/about/ (05062023)

10 MSC.1/Circ.1638 Annex, paragraph 3.4.

11 https://sea-machines.com/ai-ris/ (dated 14/12/2022)

12 https://www.orca-ai.io/solutions (dated 14/12/2022)

13 See e.g. Blue INNOship http://www.blaainno.dk/ (05062023), ECOPRODIGI / EXOPRODIGI https://ecoprodigi.eu/

(05062023), Via Kaizen https://yaramarine.com/vessel-optimization/via-kaizen/ (05062023) og Stena Fuel projekt

https://www.stenaline.com/media/stories/ai-assisted-vessels/ (05062023)

14 https://www.kongsberg.com/maritime/products/bridge-systems-and-control-centres/navigation-systems/conningdisplay/ (dated 05/01/2023)

15 https://www.trelleborg.com/en/marine-and-infrastructure/products-solutions-and-services/marine/docking-andmooring/docking-aid-system/smart-dock-laser (dated 05/01/2023)

16 https://en.wikipedia.org/wiki/Dynamic_positioning (dated 05/01/2023)

17 https://www.yara.com/news-and-media/media-library/press-kits/yara-birkeland-press-kit/ (dated 10/01/2023)

18 https://www.nippon-foundation.or.jp/en/news/articles/2022/20220602-74388.html (dated 10/01/2023)

19 IMODOCS er den officielle side der samler IMO dokumenter. Login Page | IMO Web Account (dated 07062023)

20 Se https://www.hvl.no/en/project/591640/ (Hentet 07062023) Human Maritime Autonomy Enable (HUMANE) is a project under Høgskulen in the Vestlandet in Norway. It was finalized in April 2021 and the project focused on the human aspect and the integration between human and system.

21 See http://www.unmanned-ship.org/munin/ (dated 07062023) Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) is an EU project, finished in 2016. It is designed as a pre-study of the concept of an unmanned vessel.

22 See https://yaramarine.com/vessel-optimization/via-kaizen/ (dated 07062023) The project investigates how AI can be utilized to achieve the most energy efficient route for a vessel. The project is a cooperation between industry and research, and it is placed in the Swedish research environment with participants from Chalmers, Universities of Halmstad and og Gothenburg. Further participants were Swedish Shipping, DNV, Yara Marine and Molflow.

23 See https://www.emsa.europa.eu/publications/item/3892-safemass-study-of-the-risks-and-regulatory-issues-ofspecific-cases-of-mass.html (dated 07062023) Study of the risks and regulatory issues of specific cases of MASS (SAFEMASS). The report is written by DNV GL AS Maritime at the request of European Maritime Safety Agency (EMSA). The goal is to identify new risks og challenges in regulation occurring with different levels of MASS.

24 See https://emsa.europa.eu/mass/rbat.html (hentet 07082023) Written by DNV GL at the request of EMSA, still ongoing, the goal is to develop a tool for risk assesment (Risk Based Assesment Tool (RBAT)) to facilitate member states´ approval processes for MASS designs.

25 See https://ecoprodigi.eu/ (dated 07082023) Finalized in 2020. The goal of this EU project is to investigate how digitalization can support sustainable vessel operations, in this report we use a part of the project working with the Højestene ferry.

26 See https://stenaline.com/media/stories/ai-assisted-vessels/ (dated 07062023) Operated by Stena Line, the purpose is to investigate how AI can assist the crew in reduction of fuel.

27 See https://shippinglab.dk/ (dated 07062023) Under Shipping Lab it is particularly the project about the GreenHopper ferry which is referred to in the report. The goal when developing this ferry was to reach MASS3 and demonstrate this level. The ferry was deployed in December 2022 and is operating with a safety crew during the demonstration phase.

28 See https://www.yara.com/news-and-media/media-library/press-kits/yara-birkeland-press-kit/ (dated 07062023)

Yara and Kongsberg have designed, constructed and operate the container vessel Yara Birkeland. The goal is that the vessel eventually reaches MASS3 with no crew onboard.

29 See annex 1 agenda from the first workshop.

30 See annex 2 agenda for the competence workshop

31 See annex 3 invitation for workshop on maritime cybersecurity

32 See annex 4 invitation for til seminar ”AI i sjöfartens tjänst”

33 See annex 5 5 invitation to network meeting ”Menneskets rolle i nye teknologier og driftskonsepter – Will Industry 5.0 herald the revenge of the humans?”

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MSC.1/Circ.1638 Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS)

MSC.1/Circ. 1604 Interim Guidelines for MASS tri

Chapter 1:

1 See Framework section 4

2 E.g. MSC.192(79) Performance Standards for Radar Equipment

3 Danish legislation holds a possibility for such exemptions e.g. in BEK nr 1154 af 19/11/2019, Annex 2, rule 4 and 5

4 BEK nr 1083 af 20/11/2009, Annex 1,

5 BEK nr 1083 af 20/11/2009, Annex 1, rule 5

6 BeK nr 17 af 21/07/2005, De Forenede Nationers Havretskonvention, artikel 29

7 LBK nr 1505 af 17/12/2018, Søloven § 11

10 LBK nr 1505 af 17/12/2018, Søloven § 10 stk. 2

11 Educational requirements are conditioned by size and motorpower.

12 We exempt from UNCLOS rules about innocent passage, because this is not a part of the use cases in this report.

13 UNCLOS art. 94 stk 4b and LBK 74 af 17/01/2014 §3.

14 Among others STCW A-VIII/2, part 4-1, regel 24.1

15 BEK nr 1758 af 22/12/2006

16 BEK nr 1758 af 22/12/2006, rule 15

17 Several classification societies, e.g. ABS, DNV, BV, already have rules for part of the technical system in an autonomus unit.

18 BEK nr 1154 af 19/11/2019, Annex 7, rule 15

19 MSC.1/Circ. 1638, appendix 1

20 LBK nr 74 af 17/01/2014, § 3

21 E.g. report on pollution of the marine environment acc. to Bekendtgørelse nr. 874 af 27. juni 2016, § 2

22 LBK nr 1505 af 17/12/2018, § 131

23 LBK nr 221 af 11/02/2022, § 9

24 LBK nr 221 af 11/02/2022, § 1

25 LBK nr 131 af 07/02/2020

26 E.g. straffeloven § 253, lov om sikkerhed til søs § 30, og UNCLOS artikel 98

27 BEK nr 765 af 22/07/2009

28 BEK nr 1154 af 19/11/2019, Annex 2, rule 4 and 5

Chapter 2

1 Formela, Kamil & Neumann, Tomasz & Weintrit, Adam. (2019). Overview of Definitions of Maritime Safety, Safety at Sea, Navigational Safety and Safety in General. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 13. 285-290. S. 287.

2 E.g. the IMDG code about maritime transport of dangerous goods in packaged form

3 Ref to the Polar Code

4 MSC-MEPC.2/Circ.12/Rev.2 REVISED GUIDELINES FOR FORMAL SAFETY ASSESSMENT (FSA) FOR USE IN THE IMO RULE-MAKING PROCESS

5 Ibid Anneks 1 § 1.1.2 & § 1.1.4

6 MSC -MEPC.2/Circ.12/REV.2 Figure 1.

7 See Miljøstyrelsen website: https://www2.mst.dk/udgiv/publikationer/2008/978-87-7052-814-6/html/kap01.htm#1.2.1 (dated 08062023)

8 Nidhi Kalra, Susan M. Paddock, (2016) Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability? Transportation Research Part A: Policy and Practice, Volume 94, 2016, Pages 182-193, ISSN 0965-8564,

9 Ref to Framework

10 Bek 1083 af 20/11/2009 annex 1 COLREG.

11 Please note that some harbours might have speed limits in specific areas

12 Se ECOPRODIGI / EXOPRODIGI – Work package 3 (https://ecoprodigi.eu/publications (dated 07062023))

13 Ibid

14 See Endsley's model for Situationel Awareness i Endsley, M.R. (1995) Toward a Theory of Situation Awareness in Dynamic Systems

15 See Hynnekleiv et al, 2019

16 Presentation from Zeabuz at the network meeting "Menneskets rolle i nye teknologier og driftskonsepter – Will Industry 5.0 herald the revenge of the humans?" See annex 5 in the Framework.

17 Larsson et al 2023

18 The two concepts Work as Imagined and Work as Done is used in safety research and describes how man envisions the performance of a task (WAI) and how it is actually performed (WAD). Many articles are published on this subject, see Hollnagel (2017) Can we ever imagine how work is done? I Hindsight 25

See (https://www.eurocontrol.int/sites/default/files/publication/files/hindsight25.pdf (dated 08062023)) for a short introduction to the concepts

19 It is not necessarily a simulator test. Something could be tested in a very protected environment and for others simulation would be the optimal choice. This choice is very much dependant on the maturity of the system.

20 See https://www.maritimeuk.org/priorities/innovation/maritime-uk-autonomous-systems-regulatory-workinggroup/mass-uk-industry-conduct-principles-and-code-practice-2021-v5/ (dated 14062023)

21 See https://transport.ec.europa.eu/system/files/2020-11/guidelines_for_safe_mass.pdf (dated 14062023)

22 See https://www.emsa.europa.eu/publications/item/3892-safemass-study-of-the-risks-and-regulatory-issues-ofspecific-cases-of-mass.html (dated 14062023)

23 See https://emsa.europa.eu/mass/rbat.html (dated 14062023)

24 List derived from ch. 5 Step-by-step guidance to RBAT methodology i RBAT third report_EMSA (https://emsa.europa.eu/mass/rbat.html) (hentet 07062023)

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RBAT third report, DNV-GL

SOLAS

STCW

MARPOL

IAMSAR Vol III

ISM Koden

IMDG koden

Chapter 3

1 MSC means Maritime Safety Committee and it is the committee at IMO working with and maintaining the SOLAS convention and og det overall work on safety at sea.

2 MSC 102/5/1 paragraph 4.10

3 See Framework, section 4 on the method for description of workshop.

4 Strategi for Søfartssektorens Cyber- og informationssikkerhed 2019 -2023, side 2

5 Strategi for Søfartssektorens Cyber- og informationssikkerhed 2019 -2023, side 2.

6 Ibid s.3 note 1

7 Issued in Oktober 2022

8 Held on April 18, 2023, see Framework section 4 method and Annex 3.

9 United States National Institute on Standards and Technology's Framework for Improving Critical Infrastructure Cybersecurity (NIST Framework) and IAPH Cybersecurity Guidelines for Ports and Ports Facilities are also mentioned. Cf. MSCFAL. 1/Circ.3/Rev .2 Annex, page 4 section 4.2.

10 Res. A.741(18) as amended. The ISM Code is a framework for safety management, which demands that a ship owner must prepare and implement a safety management system for the vessels for which they are responsible.

11 See chapter 2

12 IACS is an association of classification societies (International Association of Classification Societies). A classification society is authorised on behalf of the maritime authorities to handle approval procedure and issue certificates. Further to this a classification society issues a class certificate. A class certificate means that "a document issued by a recognized organisation, whereby it is certified that a vessel is suitable for a specific use or operation according to the rules and procedures, that the recognized organization has determined" (Bek nr.1294 af 24/11/2015 Bilag 1, art. 2(k))

13 MSC. 1/Circ. 1575 Guidelines for Shipborne Position, Navigation and Timing (PNT) Data processing.

14 INTERTANKO (2019) Jamming and Spoofing of Global Navigation Satellite System, London: INTERTANKO.

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Søfartens Cyber- og Informationssikkerhedsenhed.

CFCS Cybertruslen mod hjælpemidler til navigation 1. udgave november 2022

CFCS Cybertruslen mod søfart og havne 2023 februar 2023

CFCS Cybertruslen mod søfart og havne 2020 februar 2020

CFCS Cybertruslen mod skibes operationelle systemer marts 2020

CFCS Cybertruslen mod søfartssektoren januar 2019

The Guidelines on Cyber Security Onboard Ships v.4 (2020) udarbejdet og støttet af BIMCO, Chamber of Shipping of America, Digital Containership Association, International Association of Dry Cargo Shipowners (INTERCARGO), InterManager, International Association of Independent Tanker Owners (INTERTANKO), International Chamber of Shipping (ICS), International Union of Marine Insurance (IUMI), Oil Companies International Marine Forum (OCIMF), Superyacht Builders Association (Sybass) and World Shipping Council (WSC)

ISO/IEC 27001

IACS No. 166 Recommendation on Cyber Resilience

IACS UR E26 Cyber resilience of ships - New Apr 2022

IACS UR E27 Cyber resilience of on-board systems and equipment - New Apr 2022

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MSC-FAL. 1/Circ.3/Rev .2 Guidelines on Maritime Cyber Risk Management

BEK nr 1294 af 24/11/2015 Bekendtgørelse om anerkendelse og autorisation af organisationer, som udfører inspektion og syn af skibe

Chapter 4

1 This section builds on formulations from the report: Knudsen M.P., Frederiksen M.H. & Kiel J. (2023). Barriers to commercialization of autonomous technology systems: Drones, ships, and electric vehicles. Center for Integrerende Innovationsledelse, Syddansk Universitet.

2 see e.g..: https://www.transportmagasinet.dk/article/view/246290/selvkorende_lastbiler_var_i_danmark#:~:text=marts%20rullede%20seks%20selvk%C3%B8rende%20lastbiler%20igennem%20Danmark.&text=Bilerne%20k%C3%B8rte%20i%20to%20konvojer,forbundet%20til%20hinanden%20med%20radiokommunikation.

3 See e.g.: experiences from the Health project (www.sundhedsdroner.dk) or Frederiksen & Knudsen (2022).

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Chapter 6

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