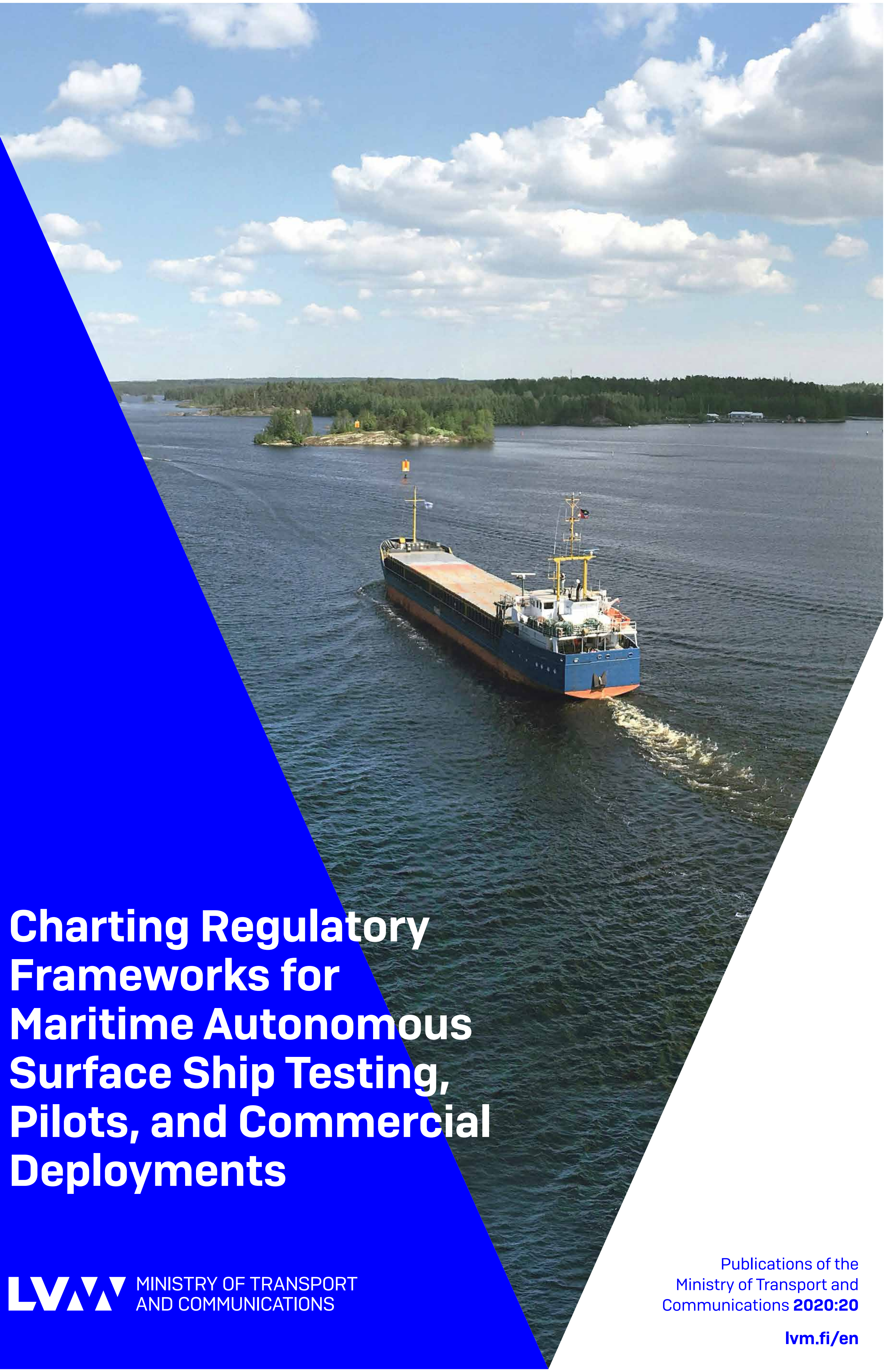

Charting Regulatory Frameworks for Maritime Autonomous Surface Ship Testing, Pilots, and Commercial Deployments

MINISTRY OF TRANSPORT AND COMMUNICATIONS

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Charting Regulatory Frameworks for Maritime Autonomous Surface Ship Testing, Pilots, and Commercial Deployments

Centrum Balticum

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Abstract

The report discusses how Maritime Autonomous Surface Ships (MASSs), ships capable of autonomous and remote operations, should be regulated. It consists of an introduction and three main chapters.

Chapter 2 introduces MASS technologies, focusing on the sensors, software components, and algorithms needed in autonomous navigation systems. The report provides an overview of the role of machine learning models in autonomous navigation systems. These are necessary especially in automating watchkeeping duties and require testing in multiple phases of the system development cycle.

Chapter 3 discusses the existing IMO, EU, and national regulatory frameworks, in the context of MASS trials and pilot deployments in test areas in the Baltic Sea. It also considers how the rules should be changed to facilitate the trials and pilot deployment. It concludes that the current rules will allow MASS trials, provided that they are approved by the authorities. Permanent MASS deployments, however, still require amendments of national and international rules.

Chapter 4 discusses theme 4, outlining the building blocks and challenges of building a future regulatory framework for MASS commercial deployments. The Chapter focuses on MASS ethics, autonomous navigation system regulation, and liability and accountability for MASSs.

Chapter 5 provides an executive summary of the main findings.

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Tiivistelmä

Raportti käsittelee autonomisten laivojen (Maritime Autonomous Surface Ship, MASS) eli laivojen, joilla on valmius operoida autonomisesti tai etäohjattuina sääntelykehystä. Raportissa on johdanto ja kolme pääjaksoa.

Pääjaksossa 2 esitellään autonomisten laivojen teknologioita, keskittyen autonomisissa navigointijärjestelmissä tarvittaviin sensoreihin, ohjelmistokomponentteihin sekä algoritmeihin. Raportissa tarkastellaan koneoppimismallien roolia autonomisissa navigointijärjestelmissä. Nämä ovat tarpeellisia erityisesti tähystykseen liittyvien toimintojen automatisoinnissa, ja vaativat testausta useassa vaiheessa järjestelmän kehityssykliä.

Pääjaksossa 3 käsitellään IMOn, EU:n ja kansallinen sääntely Itämeren eri alueilla mahdollisesti suoritetuissa erilaisissa kokeiluissa ja pilotoinneissa, sekä miten sääntelyä pitäisi muuttaa, jotta kokeilut mahdollistuisivat. Raportissa esitetään, että kokeilut ovat mahdollisia nykyisten sääntöjen puitteissa vähäisin muutoksin, jos viranomaiset hyväksyvät toiminnan. Pysyvä liikenne MASS:illa edellyttää sen sijaan sekä kotimaisia että kansainvälisiä lainsäädäntömuutoksia.

Pääjaksossa 4 hahmotellaan autonomisten laivojen sääntelyviitekehystä ja sen haasteita. Pääjaksossa käsitellään autonomisten laivojen etiikkaa, autonomisten navigaatiojärjestelmien sääntelyä ja vastuuta autonomisista laivoista.

Tärkeimmät päätelmät esitellään tiiviimmin pääjaksossa 5.

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Rapporten gäller regleringen av autonoma fartyg, dvs. fartyg som drivs autonomt eller fjärrstyrs (Maritime Autonomous Surface Ship, MASS). Den består av en introduktion och tre huvudkapitel.

I kapitel 2 introduceras olika MASS teknologier med fokus på sensorer, mjukvarukomponenter och algoritmer som krävs i autonoma navigationssystem. Det ges en översikt av maskininlärningens roll i dessa system. Maskinlärningsmodeller är helt centrala, i synnerhet vad gäller automatisering av utkiksfunktioner, och kräver testning i flera olika utvecklingsfaser.

I kapitel 3 behandlas IMO:s, EU:s och det nationella regelverket med särskild hänsyn till testområden i Östersjön. Utmaningar och möjliga lösningar diskuteras . Utredningsresultat är att nuvarande lagstiftning ger möjlighet för MASS-tester, förutsatt att de får de berörda myndigheternas godkännande. Permanent drift av MASS kräver däremot både internationella och nationella regeländringar.

I kapitel 4 kartläggs den framtida regleringsramen för autonoma fartyg och dess utmaningar. Rapporten diskuterar etiska frågor i samband med autonoma system, dryftar det framtida regelverket for autonoma navigationssystem och bedömer hur ansvarsregimen för autonoma system bör arrangeras.

Kapitel 5 ger en kortfattad sammanfattning av huvudslutsatserna.

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Contents

TO THE READER

In accordance with the Government Programme, Prime Minister Sanna Marin's Government promotes the digitalisation and automation of transport and logistics by allocating funding to experiments and influencing regulation in the field, and by developing regulatory frameworks and administration to enable digitalisation and sustainable development and a broad culture of experimentation.

The Ministry of Transport and Communications is preparing a Legislative and action plan for transport automation. It will cover all modes of transport. It is intended to be completed during 2020. The areas considered in the strategy are 1) data, digital and physical infrastructure; 2) automation development; 3) transport hubs such as ports and VTS; 4) legal measures and regulation; 5) trials and pilots and 6) view on impacts of progressing automation and indicators. The strategy will be based on evidence-based policy making. Therefore Ministry of Transport and Communications has commissioned a study on a regulatory framework for the maritime automation pilot area in the Baltic Sea and the development of intelligent and automated maritime systems, including framework for transparency, accountability and traceability of algorhitms.

Steering group of the project consisted of Maria Rautavirta, Anne Miettinen, Tomi Paavola, Irja Vesanen-Nikitin, Kirsi Miettinen, Katja Viertävä and Katja Peltola from the Ministry of Transport and Communications as well as Valtteri Laine, Esa Pasanen and Reetta Timonen from Transport and Communications Agency. The study was prepared by Centrum Balticum Henrik Ringbom, Mika Viljanen, Jussi Poikonen and Saara Ilvessalo.

Anne Miettinen, November 2020

1 Report assignment, terminology and scope

1.1 The assignment

The Finnish Ministry of Transportation and Communications commissioned Centrum Balticum to draft a report to serve as background information in future work on the regulation of maritime autonomous surface ships.

According to the assignment set out in the call for tenders, the report was to deal with four high-level Assignment Questions:

1) What are the relationships between existing IMO, EU, and national regulatory frameworks in the context of MASS trials and pilot deployments inside test areas in the Baltic Sea?
2) What are the contents of existing IMO, EU, and national rules and what is the rules' impact on possible MASS trials and pilot deployments?
3) How should the IMO, EU, and national regulation be changed to facilitate the trials and pilot deployment?
4) What kind of a regulatory framework would best support the accountability and liability of intelligent and automated maritime systems?

1.2 Report terminology

The report discusses the regulation of Maritime Autonomous Surface Ships (MASS). We use the term as the umbrella term to refer to ships capable of unmanned or remote operation. All other ships are called Maritime Surface Ships or MSSs in the Report.

During operations, MASSs may be manned, periodically unmanned, remotely operated by Shore Control Centers (SCC), subject to remote SCC oversight, or entirely autonomous. Notably, they may switch operational states during the voyages.

While the ships are called autonomous, in truth, MASS autonomy levels vary. Autonomy refers to the potential, not the actual operational state.

IMO has defined MASS as "a ship which, to a varying degree, can operate independently of human interaction".[1] The definition suggests, firstly, that it is the division of tasks between humans and technology that is in focus and, secondly, that it represents a gliding scale in which tasks may be attributed to technologies "to a varying degree".

IMO's working group on MASS has identified the following four 'degrees of autonomy':[2]

1) Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.
2) Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location, but seafarers are on board.
3) Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
4) Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

Two of the four degrees of autonomy relate to remote control, which has little to do with autonomy, *per se*, but rather relates to the location from which human functions are performed. Relocating the crew from the ship to the shore raises different legal issues than the replacement of crew functions by onboard technology, and therefore the two aspects should be conceptually separated.

Another problem, arising from the inclusion of both the crew location and the technological autonomy in the IMO's four degrees of autonomy, is that the division leaves only two parameters for each aspect, which, in turn, fails to appreciate their gliding scale. In addition to either being fully manned or completely unmanned, a ship might very well operate by means of a reduced crew or be unmanned only periodically. Similarly, rather than having to choose between mere "decision support" and "fully autonomous", as defined by IMO above, it seems quite plausible that key navigation functions of MASS will

1 IMO Docs. MSC 98/23, MSC 98/20/2 and MSC 98/20/13. See also Ringbom 2020.

2 IMO Doc. MSC 99/WP.9, Annex 1, para. 4.

be only partially performed autonomously. An example is where human intervention is available, but is only activated by alarms triggered by the system itself, e.g. where the pre-set navigational safety parameters (such as safe distances, traffic density etc.) cannot be maintained.

In order to capture such variations, a somewhat different conceptual framework is used here, separating the two main aspects of the development towards autonomous ships: onboard manning and level of autonomy. The separation highlights that the manning of a ship is not necessarily linked to the level of autonomy and vice versa. Both aspects may exist to varying degrees.

The report, first, draws a demarcation line between MASSs that have local onboard crews, i.e. crewed MASSs (CMASS), and MASSs that do not have crews, i.e. uncrewed MASSs (UCMASS). This is important, as the presence of a local crew gives the MASS the capability to transform into an MSS on short notice.

As to the onboard manning, the main legal obstacles are to be found in the rules that require crew members to be physically present on-board ships. Different rules kick in at different stages of crew reduction, but it seems, bluntly put, that it is the removal of the first and the last crew member from the bridge that gives rise to most legal complications. In particular, Part VIII of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) requires physical presence by the watchkeeping officer on the bridge at all times. This obligation is unqualified and hence violated as soon as the officer leaves the bridge. At the other end, a series of existing rules require there to be persons performing different functions on board ships, such as the master or the ship security officer. These functions can at least in theory be met, as long as one person remains on board the ship.

Autonomy, in turn, relates to the division of tasks between human beings and technology, and the manner in which technologies perform the tasks. The main legal challenge here is that certain rules require a human to be in the navigational decision-making loop. For example, the collision avoidance rules in the International Regulations for the Preventing of Collisions at Sea (COLREGs) presume a human presence by referring to the "good seamanship" of the individuals in charge of navigation and by specifying that navigational decisions are not supposed to deviate from the "ordinary practice of seamen." Another example is the maritime liability regime, which is commonly based on the premise that a human being has been at fault somewhere in the chain of events leading to an incident.

The autonomy level is not determined by the technical capabilities of the ship, but by the way in which it is operated. In between the two extremes no autonomy (full human oversight and control) and full autonomy (no human oversight or control of any kind), two additional categories are needed to illustrate the key legal distinctions. The 'monitored autonomy' (human monitoring) refers to the case where independent systems operate the ship, but crew members continuously monitor the automated functions and are expected - and required - to intervene immediately if the system fails to perform as prescribed. In this variant the autonomous system offers decision-support for the crew, but involves no alteration of their role or responsibilities. By contrast, in the 'constrained autonomy' option (human availability), the automated system operates the ship independently of human supervision, but the crew must be available to assume control when the system requests assistance. In the 'fully autonomous' mode of operation, the system operates entirely without human involvement, and crew members are not required to be available.

For immediate regulatory purposes, the critical issue is control over navigational decisions, rather than the level of sophistication of the system. The main legal distinction lies in the area where the 'monitored autonomy' moves into 'constrained autonomy'. It is at this point that the system is authorised to act on its own, without human supervision, and its role shifts from offering assistance to being in charge. The technical capabilities of the system and the percentage of time that it operates autonomously matter less in this respect.

Within the category 'autonomous' operations, the manner in which technologies make the decisions also contributes to determining the level of the ship's autonomy. Several grades of autonomy can be distinguished here as well. First, even if humans would not be immediately present as decision-makers either on board or in SCCs, humans can still control the technologies. In automation, humans determine what movements the robot makes. The movements are fully pre-programmed. In adaptive systems, the machine reacts to the external conditions according to human-determined programmed rules. In constrained machine learning systems, humans determine the methods the machine use to learn how to respond to external conditions and often verify the learning outcomes. In unconstrained machine learning, the machine learning is neither constrained nor directed: it is allowed to learn its behaviours from the outset. On the spectrum between the non-autonomous automated robots and the unconstrained and undirected machine learning entities, MASSs score low. Most MASS systems are adaptive, some close to reaching the status of constrained machine learning.

For present purposes, however, the various differentiations made within the autonomy category is legally less relevant. The key legal question here is whether we can trust any autonomous system, including purely adaptive systems, enough to be authorized to be in charge of the navigation of ships.

Consequently, the report draws the second set of demarcation lines between MASSs that are, first, operated by local crews in a Manned Operations (MO) mode, second, operated by Shore Control Centers in a Remote Operations (RO) mode, and third, operating in

Autonomous Operation (AO) mode with no active oversight from either local crews or SCCs.

> MASSs can operate autonomously in Autonomous Operation (AO) mode, in Remote Operation (MO) mode under remote control by Shore Control Centers or by local crews in Manned Operation (MO) mode.

Combined, the following typology of MASSs emerges:

Table 1. Different types of MASSs.

Operated by	Local crew present on board	No local crew present on board
Local crew	MO-CMASS	N/A
Shore Control Center	RO-CMASS	RO-UCMASS
Autonomous navigation system	AO-CMASS	AO-UCMASS

Figure 1 below is, in turn, an effort to highlight the distinction between the manning level and the level of autonomy, including the gliding scale that features in both aspects, and also to illustrate that some amount of regulatory intervention arises at a relatively early phase of development on both axes. The abbreviations used in Table 1 are included in the figure.

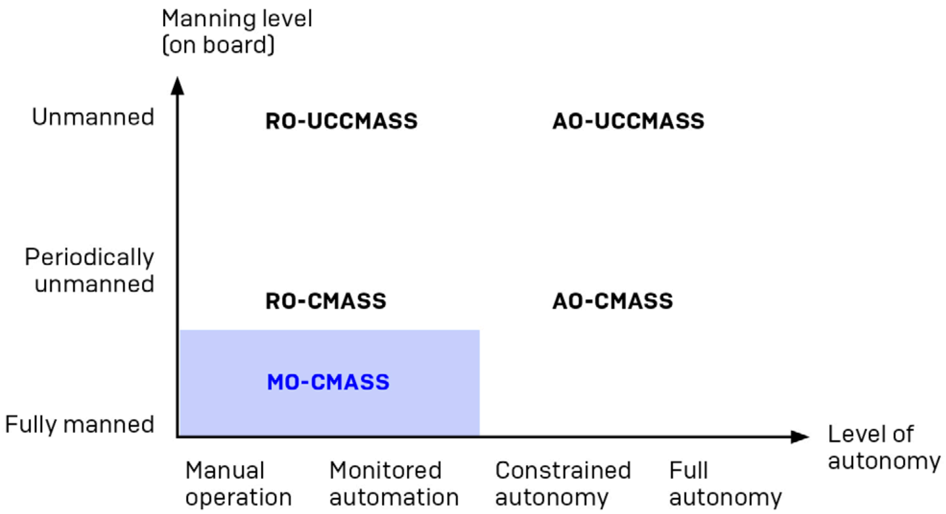

Figure 1. Separation of aspects of automation and indication of the nature of the legal challenge. Adapted from figure featuring in (Ringbom, 2018).

The onboard manning level of a ship will normally not change frequently, and a particular ship will, therefore, generally have a fairly stable manning level. By contrast, the level of autonomy refers to who the ship is actually operated, rather than its capacity to operate autonomously. The level of autonomy may change repeatedly during a single voyage, as it may depend on the sailing area, traffic conditions, and other parameters. In order to establish the autonomy level, it is thus relevant to consider how decisions on the level of autonomy are made, i.e. whether the decision is made by the system itself or the by humans. Consequently, a rigid classification of different requirements for different levels of autonomy is not helpful. Human involvement in MASS operations and, thus, MASS autonomy is a scalar phenomenon.

1.2.1 Report scope and structure

The aim of the report is to outline the contours of a solid regulatory framework for autonomous shipping operations, irrelevant their level or stage.

The framework should apply to all variations of autonomous shipping, as opposed to being limited to a specified level of manning or autonomy. As has been shown above, legal issues related to MASS do not arise only once the ship is fully autonomous or entirely unmanned. Even a partially unmanned and periodically autonomously operating ships need a new regulatory framework, as they will be confronted with many of the same legal issues that apply to fully unmanned and/or autonomous ships.

In Chapter 2, the report discusses MASS technologies to set the scene. In Chapter 3, the report addresses Assignment Questions 1 to 3. In Chapter 4, the report addresses Assignment Question 4.

Chapter 5 provides an Executive summary of the findings.

2 MASS technologies

2.1 The outline of an autonomously navigating vessel

The core technological change that takes place in the transition from MSSs to MASSs is that MASSs navigation will be performed by an autonomous navigation system (ANS).

The main tasks of an autonomous navigation system, as outlined in Figure 2, can be divided largely into two areas: situational awareness and navigational planning. Situational awareness (SA) means maintaining information of the ego vessel's own condition and navigational status, external vessels and other objects relevant for navigation, and environmental conditions. The term ego vessel is here used to distinguish the autonomous vessel under discussion from other vessels. Navigational planning (NP) uses situational awareness information as the basis for constructing global and local route plans, enabling safe and efficient navigation.

Situational awareness is based on data from multiple types of sensors. These include conventional maritime sensor systems, such as positioning sensors, radars, sonars, and Automatic Identification System (AIS) receivers, but also sensor systems used in emulating human watchkeeping, such as cameras, lidars, and microphone arrays. Generating situational awareness from sensor data requires a variety of computational operations, including sensor-specific signal processing, sensor fusion combining information from multiple sensors, and machine learning (ML)- models extracting semantic information from complex inputs, such as camera data.

The autonomous navigation systems combine existing route plans with continuously updated situational awareness information as outlined above, in order to perform three primary tasks: updating global large-scale route plans or voyage plans according to the ego vessel's current position and external conditions; adjusting the local route plan, in order to avoid collisions with external objects; and controlling the vessel's thrust and steering, in order to implement the current route plan. These tasks can be implemented using mainly conventional optimization and control algorithms, meaning that there is less need for machine learning models than in the situational awareness subsystem. However, ML models may be beneficial in providing supporting information such as long-range predictions for the future routes of external vessels.

Communication channels between the ship and shore systems are required for multiple purposes, from monitoring the vessel's systems and navigational status to remote control of the vessel to offloading stored sensor data logs. The bandwidth requirements for these different communication scenarios vary significantly, while availability of bandwidth is dependent on vessel location – typically available bandwidth is reduced as the distance from shore increases. Thus, for example monitoring generic vessel status may always be possible through satellite connectivity, while real-time remote control may be feasible only using cellular systems close to shore, and sensor data offloading may be limited to dedicated high-speed connections at port.

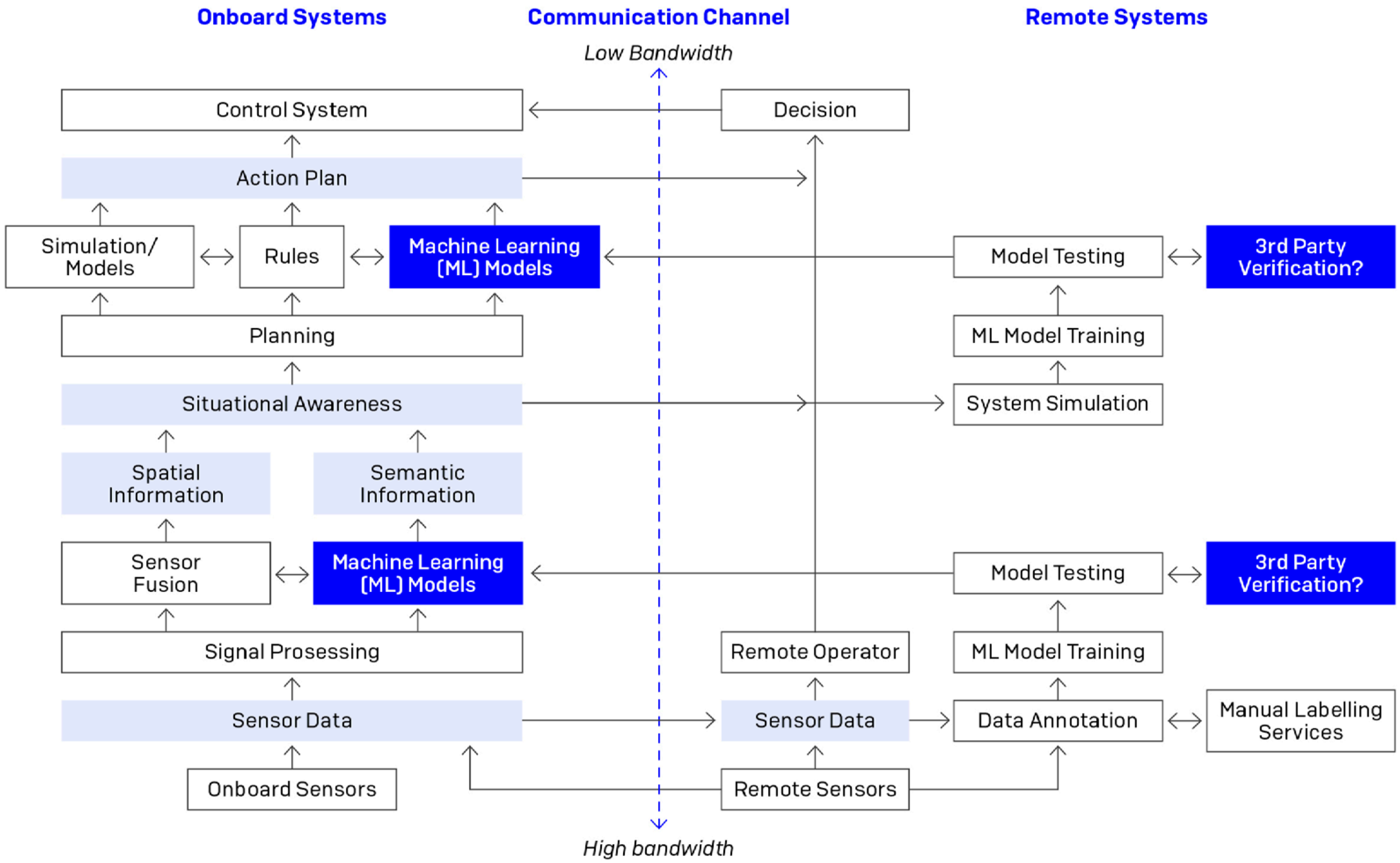

Figure 2. Overview of onboard and remote systems for autonomous navigation.

2.2 A brief introduction to machine learning concepts

Machine learning models are computer algorithms that can learn and improve in a given task based on experience, without being explicitly programmed. As learning is a core characteristic of ML models, machine learning approaches are typically categorized according to the type of learning process applied. Common ML categories are supervised learning, unsupervised learning, and reinforcement learning.

Supervised learning means that an ML model in training is provided with both data and metadata (sometimes called labels) indicating the inferences the model should produce from the data. In unsupervised learning, the model is not provided with labelled data, but learns patterns or structures in the data, being able e.g. to cluster data points. In reinforcement learning, the model in training is able to perform actions in an environment providing rewards depending on the action, resulting in the model learning the action strategy that will maximize its cumulative reward.

Computationally, ML models can be implemented in many forms or architectures, but modern state-of-the-art models are commonly implemented using some form of artificial neural networks (ANN). The design of ANNs is inspired by biological neural networks in the brain, and typically consist of large numbers of successive layers of computing elements called neurons, joined by weighted connections called synapses (or simply weights). Due to the large numbers of neuron layers in modern artificial neural networks, the ANNs are commonly called deep neural networks, and associated machine learning is typically called deep learning.

Deep learning models applied for example in modern computer vision tasks may contain hundreds of neuron layers and tens of millions of parameters to be optimized during the training process. This means that it is very difficult to analyse such models for example in terms of explaining why they produce a given output for a specific input, and how a given change in the input will affect the output. It is also, in practice, not feasible to manually correct a model producing an undesired output for a given input, by manually adjusting the model configuration. Improvements or corrections to model behaviour happen through the model training process, i.e. by configuring the model using large numbers of training examples.

Due to these characteristics, ML models are sometimes called black box models. This also means that the performance of ML models cannot be ensured using conventional software verification and validation methods. Rather, their performance needs to be evaluated using statistical test procedures. This aspect of machine learning models is often seen as problematic for the regulation and verification of systems deploying ML models as part of their software.

Applications of ML models that are potentially relevant for autonomous navigation systems include signal classification, object detection, semantic segmentation, regression models, and learning optimal control strategies by reinforcement learning.

In brief, classification means assigning a label to input data. For example, when given an image, a classification model should produce a label indicating what is in the image.

Object detection combines object classification with estimation of the locations of objects in the input data. For example, in computer vision, an object detection model typically produces a list of minimal bounding rectangles and classifications for all objects in an image. It should be noted that this applies only for object classes which the model has been trained to detect, while it should ignore all other types of objects. Semantic segmentation models classify all signal elements in an input according to object type. For example, in computer vision, a semantic segmentation model labels every pixel of an image according to what object type they are part of.

Regression models are used to make typically continuous-valued numerical predictions based on input data. For example, applied on time series data, such as the trajectory of a vessel, a regression model might be used to predict the location of the vessel at a given time in the future, or the time of arrival of the vessel to a given location.

Finally, reinforcement learning -based control models can be used to learn desired behaviour, based on complex input data, in applications where it is difficult to formulate explicit rules between the input and the desired action. Such models have been studied in, for example, autonomous vehicles performing navigation tasks, such as lane changes, overtaking, or parking.

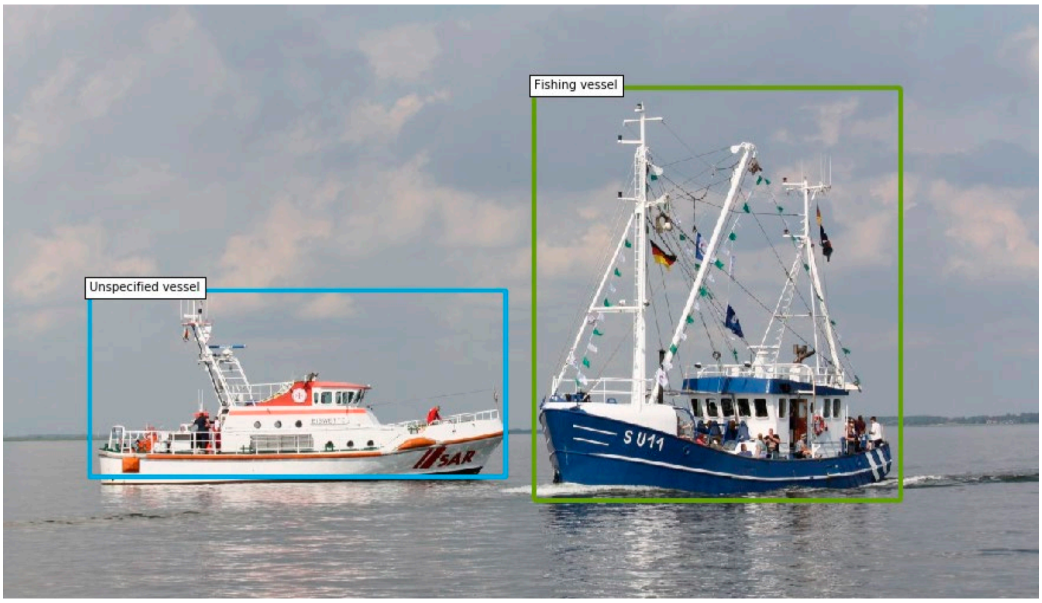

Figure 3. Example of object detection. The output of a visual object detection model is typically in the form of bounding boxes, or minimal bounding rectangles, and classifications for objects in the classes of interest the model is trained to detect.

2.3 Autonomous vessel sensor systems and their limitations

2.3.1 Overview of sensor data in autonomous operations

As outlined e.g. in (Poikonen 2018), the range of sensors in situational awareness systems typically include at least perceptual sensors such as cameras, lidars, radars, sonars, and positioning sensors such as Global Navigation Satellite Systems (GNSS) and inertial measurement units (IMU). Additionally, the VHF radio-based automatic identification system (AIS) is not strictly a sensor but is commonly used as a data source to support sensor fusion. Other sensors applicable in autonomous vessel systems may include e.g., sound receiving systems for detecting and identifying external audio signals, weather sensors, which may be used for monitoring navigation conditions and the operational conditions of other sensors, and sensors monitoring the vessel's internal state, e.g. engine health. However, this document focuses mainly on the most common sensors used for situational awareness and autonomous navigation, as described in more detail below.

Figure 4 lists typical sensors used in autonomous vessels, as well as the primary applications for the data they produce. However, it should be noted that many sensors can be used also for secondary purposes in sensor fusion, or to add redundancy against sensor failures. For example, while the typical purpose of a radar system is to monitor external vessel traffic, it is also possible to combine radar measurements with map information for coarse location estimation, which may be necessary when primary onboard positioning sensors such as GNSS/INS are unavailable.

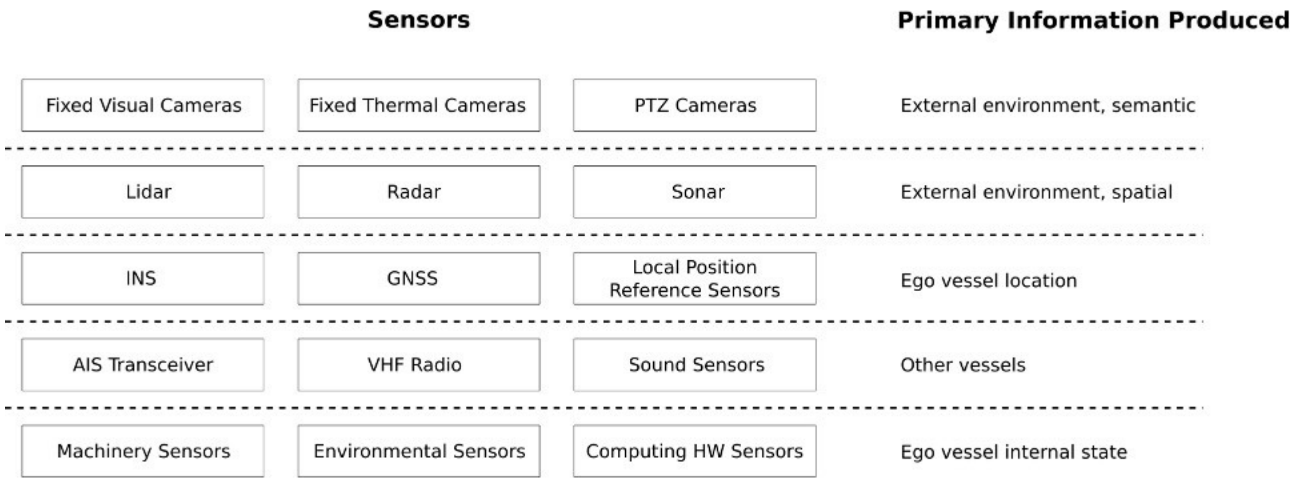

Figure 4. Typical sensors and types of information.

2.3.2 Common sensor and data types

2.3.2.1 GNSS + INS

Global Navigation Satellite Systems (GNSS) is an umbrella term covering satellite navigation systems such as U.S.-based GPS (Global Positioning System), Russian GLONASS (GLObal NAvigation Satellite System), European Galileo, and Chinese BeiDou Navigation Satellite System (BDS). GNSS systems are based on receiving radio signals from constellations of satellites and using these to determine the receiver's location globally. GNSS systems require a line of sight between the receiver and satellites, meaning that the accuracy and availability of GNSS positioning may vary according to vessel location and nearby obstructions. To improve the robustness of location estimation, GNSS systems are often combined with Inertial Navigation Systems (INS), which use Inertial Measurement Units (IMU) to estimate the movement of the vessel and integrate this data in order to maintain consistent positioning estimates.

2.3.2.2 AIS

AIS (Automatic Identification System) data is transmitted over VHF radio frequencies as mandated under the SOLAS convention (The International Convention for the Safety of Life at Sea, Chapter V, Regulation 19) for all passenger vessels and cargo ships of 300 gross tonnage or more (with limited exceptions), as well as fishing vessels of more than 15 meters in length. AIS messages contain dynamic information on the current status of a vessel, such as position, course over ground, and speed over ground as obtained from positioning systems such as GNSS + INS, and also more general ship and voyage -related information, such as the ship type and current destination. AIS-based data is useful for situational awareness, but its availability, correctness, and timeliness are not guaranteed for all vessels. Thus, AIS cannot be considered sufficient information for autonomous navigation, although it is highly useful input data for sensor fusion.

Historical AIS data can also be used to develop predictive models for navigation planning systems. For example, machine learning models can be trained with AIS data from a selected geographical region to predict vessels' future trajectories, which is useful for collision avoidance, where determining the Closest Point of Approach (CPA) and Time of Closest Point of Approach (TCPA) of other vessels accurately is critical.

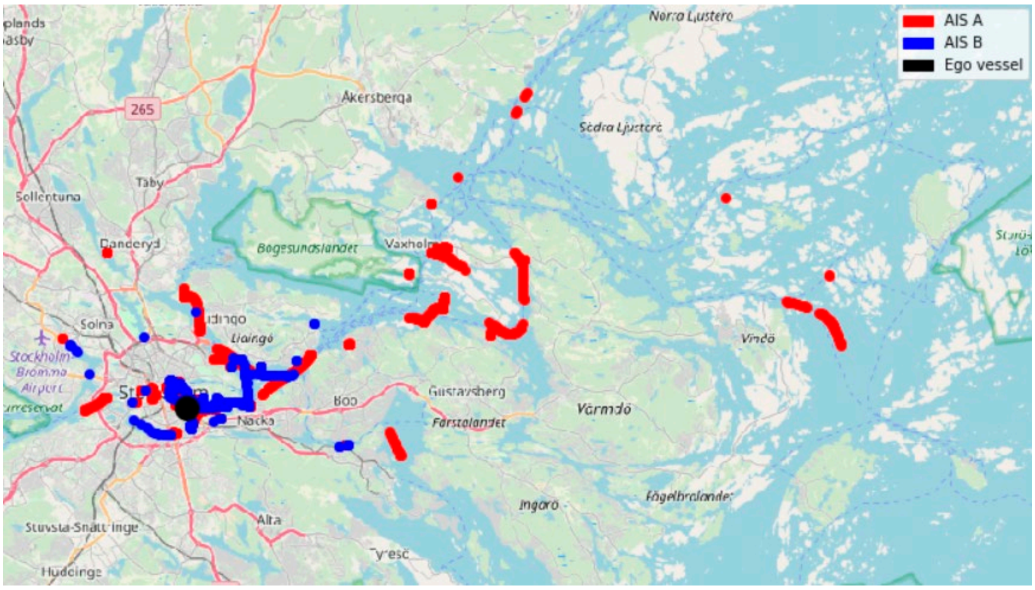

Figure 5. Example of AIS message source locations as recorded by a receiver marked with a black dot. The farthest messages are received from up to 40 km away. Red dots mark messages from AIS type A systems which are mandatory on commercial systems, while blue dots mark message from AIS type B systems.

2.3.2.3 Radar

Radar systems are commonly used on board vessels to detect and track traffic and other surrounding obstacles. COLREGs requires radars to be used in keeping a general lookout, especially in restricted visibility. However, radar monitoring does not generally replace visual lookout. Radar sensors provide capability for detecting and tracking moving objects at long range (up to tens of nautical miles, depending on the sensor), but their resolution, or ability to distinguish separate targets, decreases along with increased operation range. Furthermore, not much semantic information (e.g. what types of objects are detected) can be generally obtained from radar signals, as radar systems typically categorize targets according to a relatively coarse set of classes, such as moving objects, static obstacles, and noise caused e.g. by environmental conditions. In autonomous navigation systems, it is beneficial to use sensor fusion to combine radar data with inputs containing more semantic information, such as AIS messages and camera-based object classification.

Recently, machine learning models have also been considered for processing marine radar signals. These models offer potential benefit e.g. in improving the classification of objects in radar signals (Kim and Kim 2019) and in removing environmental noise, such as sea clutter (Callaghan, Burger, and Mishra 2017).

2.3.2.4 Cameras

In an autonomous navigation system, cameras are used to fulfil the role of visual lookout in conventional watchkeeping. Different types of camera systems are needed for different lookout tasks. For example, arrays of multiple camera sensors may be needed for 360-degree lookout around the vessel, while long-range lookout comparable to a human using binoculars can be implemented using Pan-Tilt-Zoom (PTZ) cameras. Camera systems may also operate either in visual light or in infrared or near-infrared frequency ranges, enabling imaging in low light or in the presence of atmospheric conditions reducing visibility. The main challenge with camera systems in marine applications is that the increase of operating range, i.e. reliably detecting features at longer range while maintaining general lookout capability, requires increased camera resolution, which, in turn, increases the demands for computational capacity, data transfer bandwidth, and storage capacity.

Camera sensors enable computer vision, the role of which in intelligent vehicle systems is discussed in detail e.g. in (Ranft and Stiller 2016). From the perspective of situational awareness, the types of information obtainable from perceptual sensors can be divided into two classes: semantic (what objects are represented in the data) and spatial (where in the real environment the objects in the data are). Camera systems generally provide rich semantic information, but relatively coarse spatial information. Typical camera processing tasks in autonomous navigation systems include object detection and classification, which aim to locate and identify specific types of visual features from images, and semantic segmentation, which aims to classify all parts of an input image., and is thereby useful for a more general scene understanding. Implementing these tasks in a robust manner is one of the primary applications of machine learning models in autonomous navigation systems.

2.3.2.5 Lidar

Light detection and ranging (lidar) sensors produce three-dimensional point cloud representations of their surroundings by rapidly performing many range measurements along a repeated scan pattern. Lidars are useful for situational awareness, as they provide both semantic and spatial information. Combined with positional data from inertial measurement units, lidar point clouds can be accumulated over time to form detailed 3D representations of static environments, which enable e.g. the automation of navigation tasks requiring precise monitoring of vessel surroundings, such as berthing. Furthermore, although lidar point clouds do not inherently contain information on object colour or fine surface details, objects can be detected and classified from point sets using machine learning models such as artificial neural networks, as demonstrated in (Qi et al. 2017).

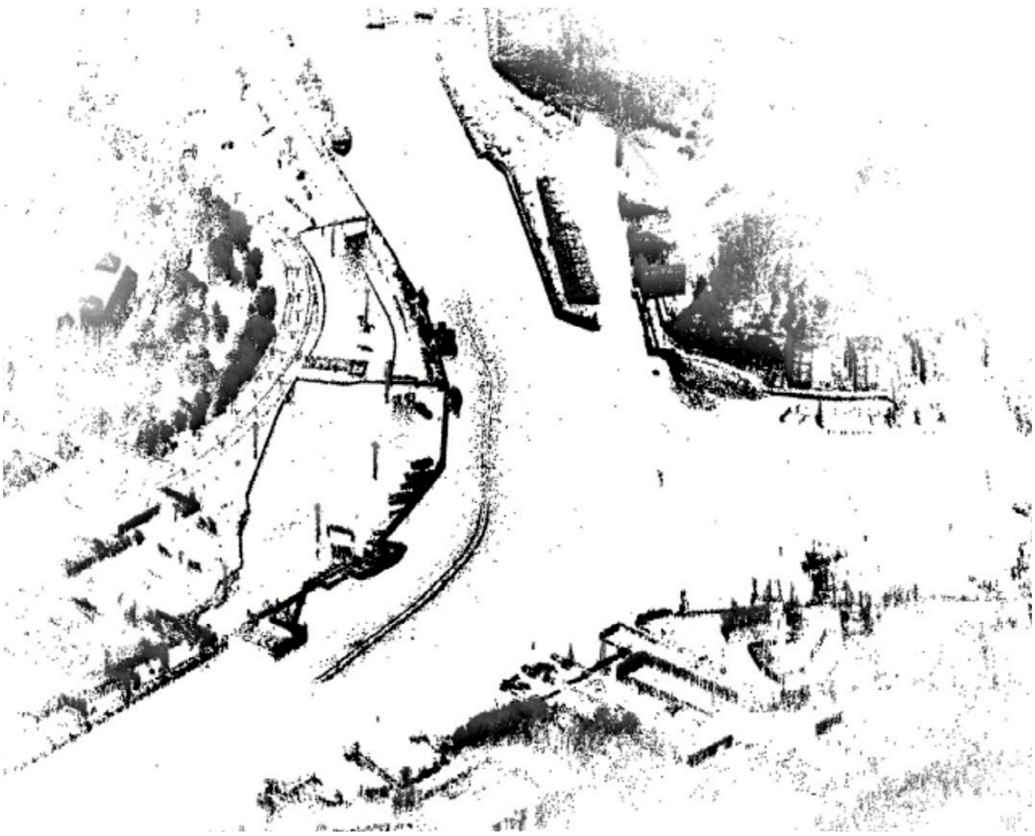

Figure 6. Visualization example of lidar point cloud data recorded over a three-minute period on board a vessel traveling along the river Aura in Turku, Finland (Poikonen 2018). The track visible in the water is the wake left by the vessel during the measurement.

Compared to radar and camera systems, current lidar sensors are of limited use in maritime environments for tracking vessel traffic due to their limited range and spatiotemporal resolution. However, at short to medium range (e.g. up to hundreds of meters, depending on the sensor) they provide highly accurate data applicable for navigation planning, collision avoidance, and position estimation.

2.3.2.6 Microphone arrays (acoustic cameras)

Sound sensing and sound signal processing can be applied for object and event (e.g. warning sounds) detection, as well as localization and identification of objects, such as other vessels. Fusing sound measurements with camera, radar, and lidar data can be used to make situational awareness systems more tolerant to changing weather conditions, and to improve the robustness of object localization and classification. Incorporation of sound sensing is also needed to make an autonomous or remote-controlled ship more clearly compliant with existing marine regulations mandating lookout based on sound.

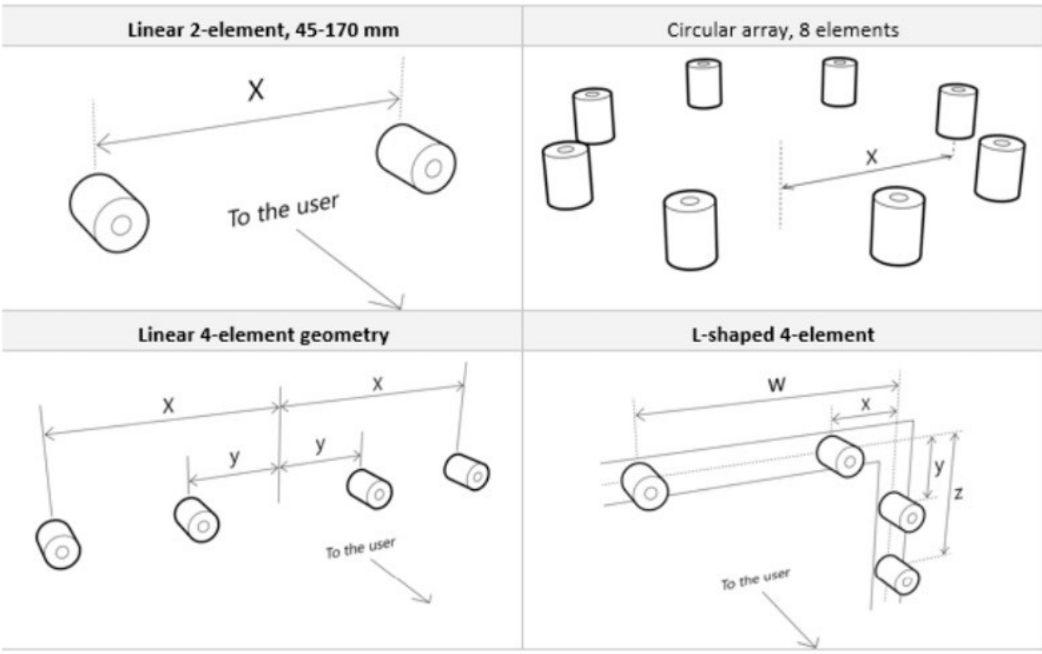

Figure 7. Examples of simple microphone array geometries (Source: Microsoft documentation on Windows 10 microphone array support, http://download.microsoft.com/download/9/c/5/9c5b2167-8017-4bae-9fde-d599bac8184a/micarrays.doc).

To enable estimation of the direction of incoming sounds, an array of several sound receivers (e.g. microphones or hydrophones) are required. Such sensors are sometimes also referred to as acoustic cameras. Signal processing tasks for multichannel audio data captured by acoustic cameras include sound detection, classification, and direction of arrival estimation. While these can in many cases be implemented using conventional signal processing algorithms, machine learning models may also be used for classification of different types of sound sources or detecting specific types of sounds.

2.3.3 Signal processing and sensor fusion

The computational operations and algorithms used to form situational awareness for navigation planning can be divided generally to sensor-specific processing and sensor fusion operations. Sensor-specific processing requirements depend on the sensor type, and will not be considered in detail here. However, some typical computations of sensor-specific processing include signal processing for correcting hardware imperfections (e.g. correcting camera lens distortions), noise removal algorithms, signal enhancement algorithms, synchronizing sensor inputs to a global timing signal, and sensor signal registration, as well as object detection, classification, and tracking.

Sensor signal synchronization and registration are essential operations for subsequent sensor fusion. These ensure that information from multiple types of sensors can be aligned spatially and temporally, and analysed jointly. Here, sensor signal registration means transforming the sensors' measurements from distinct sensor-centric coordinate systems to a shared global coordinate system. For example, radar signals can be mapped from the intrinsic radial coordinate system, indicating the distance and angle of a target, to global latitude and longitude coordinates using knowledge of the sensor's location on the vessel, and positioning information from the GNSS and INS sensors. Even camera sensor information can be mapped with varying accuracy from the image plain (pixel horizontal and vertical coordinates) to latitude, longitude, and altitude coordinates, depending on how well the semantic content of the image is understood (e.g. using semantic segmentation ML models).

Sensor fusion -related signal processing tasks include object detection using combined multimodal sensor data (early fusion detection), joining semantic and spatial data obtained from different sensors using conventional detection methods and ML models, combining object-specific measurements, such as locations and speeds, and tracking and predicting object locations over time. The Kalman filter is the most common method of combining noisy measurements from multiple sensors to estimate e.g. object locations and speeds. It models the noise of the sensor inputs over consecutive measurements and aims to combine these in an optimal way. Kalman filters can be applied in many ways in sensor fusion for situational awareness. Typical examples include combining GNSS and INS signals for ego vessel location estimation, and combining radar, AIS, lidar, and camera -based object location measurements to track surrounding ship traffic.

In addition to providing more comprehensive or more accurate information on object types and locations, a significant task for sensor fusion in an autonomous navigation system is to enable redundancy. An autonomous system needs to allow for possible failures in sensors or subsystems, ensuring the ability of the system to operate safely until the failed sensor or subsystem has been replaced. It is important to be able to perform critical tasks, such as providing situational awareness for navigation or estimating the ego vessel location, using multiple sensors, in order to allow graceful degradation of performance if critical sensors fail. For example, Figure 8 illustrates sensors applicable in estimating locations of other vessels (top) and the ego vessel (bottom). For example, while AIS and radar measurements combined with information on the ego vessel's location are most commonly used for detecting other vessels, also lidars, camera systems, and acoustic cameras provide useful information. Similarly, although GNSS + INS is the primary source for ego vessel location information, it is possible to apply e.g. computer vision and radar measurements combined with map data as a fallback for location estimation.

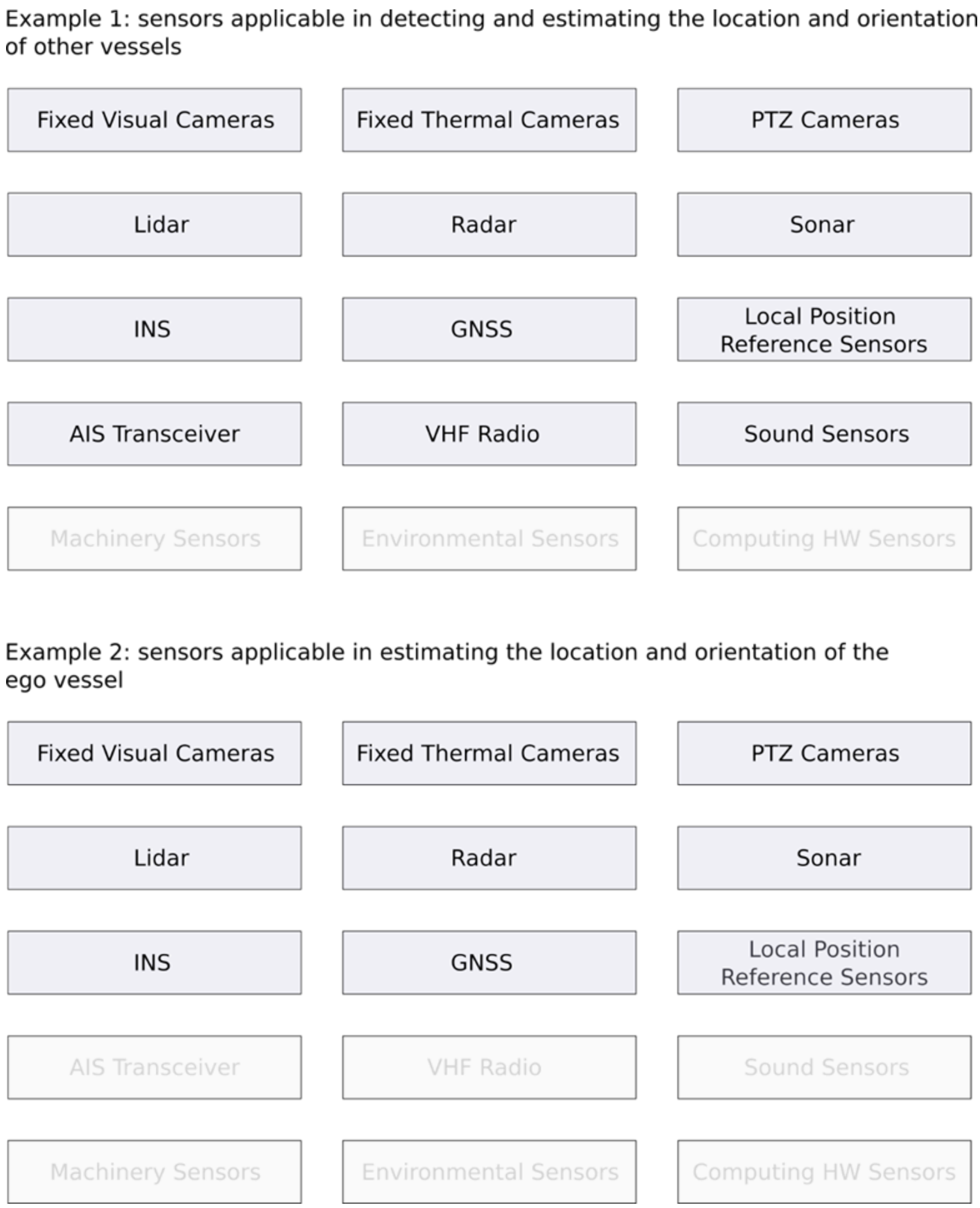

Figure 8. Examples of sensor redundancy in situational awareness.

2.3.4 ML models for sensor signal processing

The most common applications for machine learning in sensor signal processing for situational awareness include object detection, classification, and semantic segmentation. Object detection means locating features from pre-defined object classes, such as ships, sea marks, emergency signals, or people, etc. in sensor data. ML models for object detection can be applied for many types of sensors and input signal types, including radar, lidar, cameras, and audio sensors. The most common use case is detecting objects from camera images, which in practice requires the use of modern ML models in order to achieve state-of-the-art accuracy.

Camera data is rich in semantic information and can be used to classify fine features relevant for navigation, such as ship types and various visual signals. However, all object classes to be detected by a ML model need to be defined for the model and trained individually using sufficiently large sets of training data. Typically, such training data needs to be collected from sensor systems operating in real conditions, and labelled manually by humans, which is a costly and laborious process. Thus, many navigation-related visual classification tasks that are easy for humans can be demanding for automation development. Such tasks include identifying signal flags, flares, and other ships' operational states, for example whether a sailboat is engine-powered or sailing, as well as detecting unknown debris in the water and classifying the heading of stationary ships.

It is also important to note that in order to achieve best possible accuracy, ML models can be trained according to expected operating conditions, i.e. with data corresponding to the local environment where the system is deployed. This may set additional challenges for model training, validation, and regulation, as it requires maintaining local variants of models and datasets for model testing and verification. It may in practice be difficult especially for possible third-party regulators to maintain independent test datasets for comprehensive testing of localized models.

Generally, metrics for evaluating object detection models need to take into account several factors, such as object location estimation accuracy, probabilities of correctly detecting an object (true positive detections), falsely detecting non-existent objects (false positive detections), and classification accuracies for individual object classes. It should be noted that these are statistical variables, which can be evaluated only using sufficiently large test data sets. Also, the relevance of different performance metrics may depend on the specific use and purpose of the model in the navigation system. For example, reliable classification between different types of cargo vessels may not be critical for basic navigation planning, whereas visual identification of aids to navigation, such as lateral and cardinal marks, may be a critical system requirement.

The achievable performance of ML models for feature detection is fundamentally limited by the resolution of the input data. Thus, when setting performance requirements for such systems, it is necessary to also specify the characteristics of the target objects sufficiently. For example, a visual object detection system performance requirement might be formulated as: 'the system should detect a ship of overall beam 30 m and length 300 m at a distance of 1000 m with probability larger than 99 %, with an overall false positive probability of less than 1 %'. Furthermore, it is necessary to specify what is considered a successful detection. For example, in visual object detection tasks this could be 'the area of intersection of the detected object and the true object area divided by the union of these areas is greater than 80 %'. This Intersection over Union (IoU) metric is widely used for estimating the accuracy of object size and location detection. Based on such requirements, sensor systems can be engineered to produce sufficient resolution for properly trained ML models to fulfil the performance criteria.

Similar resolution limitations are valid for all sensors used for object detection, but the metrics defining the sensor resolution depend on the type of data produced. For example, limiting factors for lidar data are measurement range and point cloud density, and for radar measurement – range, as well as radial and angular resolution. The limiting factors for acoustic cameras, in turn, are the number and geometry of microphones in the array, their sensitivity and noise characteristics, and sampling frequency.

As outlined above, the main role of ML models used for situational awareness is to perform various signal processing tasks in order to extract information from sensor data. From this perspective there are no inherent ethical concerns in the usage of ML models. As outlined above, the models either work according to given performance specifications or not, and the performance can be verified with statistical analysis of models applied over sufficient data sets.

However, ethical concerns may arise in designing the requirements and specifications for the signal processing subsystems in an autonomous vessel. Regarding ML model applications, there is typically a trade-off between system complexity and cost, and level of detail in information extracted from sensors. By level of detail we mean e.g. the range of objects or events the ML models are trained to detect and classify. For example, COLREGs specify many requirements for watchkeeping, requiring dedicated models or subsystems, such as detecting and identifying alarm sounds (horns, gongs, gunshots), flag signals, signal lights, etc. Subsequently, the following question is relevant: Should an autonomous vessel be able to detect and understand all such means of communication, or which subset of these should be automatically identified? A recommendation for future regulatory work is that there should be a clear definition of which existing or new watchkeeping requirements are applied for autonomous ships, and technical definitions of what such requirements mean e.g. for automated object detection, as discussed above.

Another system design and specification aspect with potential ethical effects is the selection of algorithm parameters, such as decision thresholds for accepting detections from object detection models. This may involve trade-offs between safety and smooth navigation, since accepting object detections with low prediction confidence may cause false positive detections, resulting in unnecessary collision avoidance, while high confidence thresholds may cause real hazards to be ignored, compromising navigation safety. To reduce this risk, it is important to ensure that the data used in model training and system testing has sufficient coverage of real-world scenarios, and that all models are well trained and tested.

2.3.5 Examples of challenging scenarios for sensor fusion and machine learning systems

2.3.5.1 Difficult environmental conditions

The same kind of conditions that affect watchkeeping and navigation in manned vessels are typically also challenging for autonomous navigation systems. While sensor technologies may provide some new capabilities, such as night vision (thermal cameras) and accurate distance measurements (lidar), low visibility conditions, such as heavy fog, snow, or rain, are still challenging for sensor systems, which therefore cannot be expected to provide observation capabilities that are significantly superior to that of humans. For example, typical visual sensors, such as cameras or even lidars, may provide little useful information for sensor fusion in dense fog or snowy conditions, which means that the system must rely e.g. on radar and sound reception, as would human operators. As weather conditions may also affect the operation capability of the sensors, some mechanisms need to be in place in order to ensure, for example, that optical systems are not obstructed by dirt, ice, snow, or water.

2.3.5.2 Spoofing, jamming, sensor failures

The primary sensors used in autonomous navigation for ego vessel location estimation and situational awareness are susceptible to malicious external influence in the form of spoofing or jamming attacks. For example, satellite positioning signals can be jammed or spoofed using strong counterfeit signals, AIS allows broadcasting false information or fabricating non-existent targets, and radars can be jammed by transmitting interfering noise or false information. Thus, a minimal sensor set, e.g. consisting only of GNSS + INS sensors, AIS, and radar, is not sufficient for autonomous operation. An autonomous navigation system needs to have redundant sensory capability in order to be able to detect and counter spoofing and jamming, as well as sensor failures.

Sensor failures could be handled simply by including redundant copies of critical sensors, but this does not generally help against spoofing or jamming, where even detecting the failure state may require input from other types of sensors. However, camera systems and lidar sensors are potentially useful as redundant sources of information for situational awareness. With suitable computer vision algorithms and machine learning models, they can be used to estimate or check the ego vessel location, and to detect or verify the presence of external objects, although with possible reduced accuracy compared to the primary sensors used for these purposes. Also, spoofing or jamming camera and lidar systems is difficult, short of physically incapacitating the sensors, which in turn should be detectable by the navigation system.

2.3.5.3 Detecting exceptional events and signals

Figure 9 illustrates several auditory and visual signals used in maritime navigation. All of these are nontrivial to detect and identify using automatic sensory systems, and many would require development of dedicated algorithms or ML models. The degree to which an autonomous vessel should be designed to understand such conventional signals is a significant question for maritime regulation.

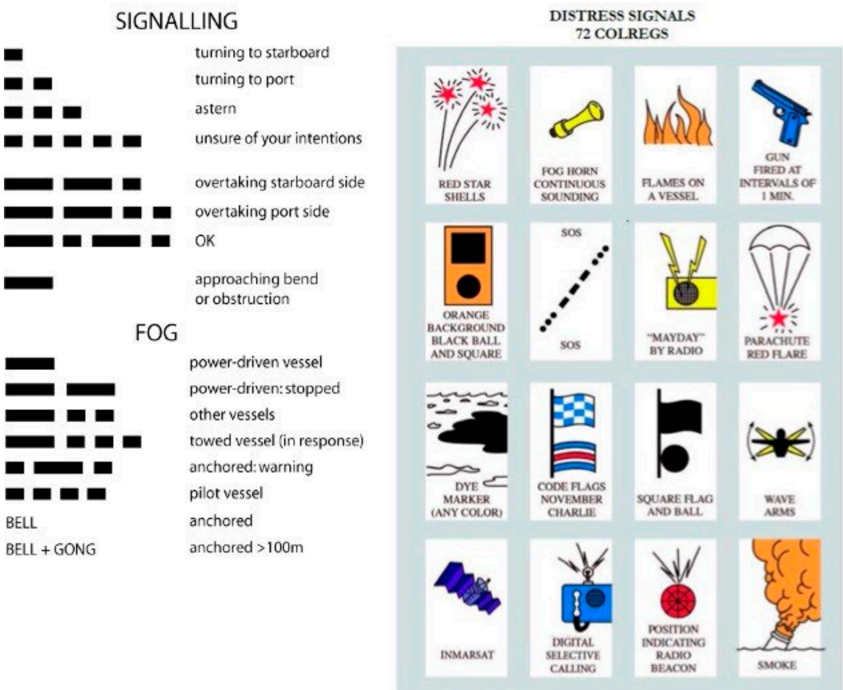

Figure 9. Various maritime signals (Source: US Coast Guard, 2013).

2.4. Navigation systems overview

2.4.1 Autonomous navigation tasks

The primary tasks of an autonomous navigation system are path planning, collision avoidance, and manoeuvring control. The objective of path planning, as outlined for example in (Chen et al. 2020), is to provide an optimal route for the ship to navigate between selected locations, considering various factors, such as distance and travel time. Path planning can be classified into two major categories: global path planning and local trajectory planning. The aim of global planning is to provide a general macroscopic route, considering various factors, such as geographic characteristics of the route and meteorological information.

The aim of local trajectory planning is to provide a specific short-term trajectory according to specific objectives, such as collision avoidance. The term collision avoidance typically refers to local trajectory planning aiming to avoid collisions with other vessels. However, local trajectory planning should also consider e.g. weather conditions in order to avoid routes where the vessel cannot safely manoeuvre.

Manoeuvring control is a control system connected to the steering and propulsion systems of an autonomous ship. Its task is to keep the ship as close as possible to the planned trajectory in the presence of environmental disturbances such as waves and currents. This is especially significant in or near port areas and hinterlands with congested waterways. (Haseltalab and Negenborn 2019)

2.4.2 Typical methods used for path planning, collision avoidance, and manoeuvring control

Path planning and collision avoidance methods fall generally into the category of optimization algorithms, where the output is a trajectory optimized over selected cost functions, such as total distance travelled, voyage time, and closest point of approach to hazardous obstacles. The optimization algorithms need to take into account a range of variables, such as land areas along the route, weather conditions, sea currents, and other vessels. From this perspective, the main difference between global path planning and collision avoidance is that a global plan can be made initially for a long voyage segment, while local path planning or collision avoidance needs to be constantly recomputed according to dynamically changing external conditions. It is the task of the situational awareness subsystem of the autonomous ship to provide the information on external conditions required for path planning.

As their tasks are similar, global and local path planning can be implemented using similar computational optimization algorithms. Typical approaches include artificial potential fields (APF), heuristic optimization, and computational geometry methods (Chen et al. 2020). APF methods involve constructing a potential field of the environment, where the destination of the path generates global attractive forces to the ship, while obstacles (stationary or dynamic) generate local repulsive forces. These can be adjusted also to account for optimization targets, for example following COLREGs-based collision avoidance rules.

Heuristic planning methods are based on optimizing the planned trajectory using approximate measures (heuristics) to estimate the cost (for example remaining travel distance) of traveling from any possible location to the desired destination. Variants of the A* algorithm, developed originally for path planning in mobile robotics, are widely used heuristic planning methods. These algorithms represent the planning area as a graph (e.g. an occupancy grid containing allowed and occupied locations for the ship's path) and use a tree search to find an optimal path to the destination, while considering the heuristic cost of each location along the route.

Computational geometry methods, such as Voronoi diagram based algorithms, have the advantage of being able to represent complex environments more accurately than e.g. the occupancy grid -based graphs commonly used with A* algorithm variants. Their use in dynamic environments for mobile robotics path planning was recently discussed e.g. in (Ayawli et al. 2019).

2.4.3 The role of ML models in autonomous navigation tasks

Reinforcement learning models are the primary class of machine learning models that could be applied to directly control a vessel. Reinforcement learning ML models have been considered for various control system applications, such as autonomous driving, industry automation, robotics, and learning games. The most relevant field of comparison for autonomous ships are applications in autonomous driving. A recent survey of deep reinforcement learning applications in this domain is given in (Kiran et al. 2020). ML-model applications for autonomous driving tasks considered in literature include *e.g.* motion planning, overtaking, intersections/merging, lane changes, lane keeping, and automated parking.

Reinforcement learning models may be useful in complex environments when it is not feasible to apply conventional computational optimization or rule-based systems for path planning or system control. However, control applications relying only on reinforcement learning models can be challenging in safety critical applications, due to the typical characteristics of machine learning models, such as lack of explainability and predictability of model behaviour.

It can be argued that direct control of ship manoeuvring using ML models is not necessary in autonomous ships, since vessel control can be implemented using conventional optimization algorithms, rule-based systems, and physical models for ship dynamics. As outlined in (Geng et al. 2019), autonomous ships can, in comparison with autonomous land vehicles, obtain better information on surrounding traffic, due to e.g. the availability of AIS data, and have more options for path planning, as there is no explicit lane constraint in the waterway. However, autonomous ship path planning needs to be more predictive than that of autonomous ground vehicles, due e.g. to larger inertia and the effects of hydrodynamic forces.

Taking these characteristics into account, even if not used for direct control by deep reinforcement learning, ML models may be useful in autonomous navigation systems for long-term prediction of surrounding traffic. Location-specific navigation behaviour of other vessels can be learned from large historical datasets, for example from AIS. This does not even require onboard data collection, as AIS data is globally available through various terrestrial and satellite receiver networks. Time series regression models, such as long short-term memory (LSTM) neural networks, are applicable in producing accurate predictions based on the current locations, headings, and speeds of other ships, as considered recently for example in (Ding et al. 2020). Predictive models are commonly used also for ego vessel dynamics in model predictive control systems to accurately steer the vessel according to a planned trajectory. However, ML models are not generally required for this, as the related hydrodynamic forces can be modelled physically.

There is a potential risk in relying on ML-based long-term trajectory predictions for collision avoidance, as accuracy of such predictions cannot be guaranteed. A safe approach could be e.g. for the navigation system to be configured to use such models only for added caution in local path planning and collision avoidance, in case long-term predictions show possible cross traffic along the ego vessel's planned trajectory.

2.5 Communication channels overview

The sensors outlined above produce data at different rates, and the need for transmitting data from ship to shore varies between sensors and operation scenarios. Below we outline key operating scenarios from the perspective of sensor data processing and communication, and the resulting communication channel requirements and technical options.

2.5.1 Remote control

It can be argued that a system for remote control of an unmanned ship, or e.g. remote pilotage of manned vessels, should provide the remote pilot with a level of visibility and control as close as possible (or superior) to being on board the controlled vessel. This addresses the fundamental problems of limited feedback and feedforward information in remote piloting, as discussed in (Bruno and Lützhöft 2009). In addition to fast video encoding on board the vessel, and decoding in a shore control facility, the most significant technical requirement for such remote operation is the availability of sufficiently high-bandwidth and low latency wireless connectivity between the vessel and control facility.

There have been demonstrations of remote-controlled vessels with transmission of camera data, lidar data, positioning data, and sensor fusion -based situational awareness data. The total order of magnitude for the bandwidth of these data feeds is of the order of tens of megabytes per second. Such bandwidth can be achieved with existing cellular networks (4G or 5G). However, due to the criticality of remote-control functionality, redundant connectivity needs to be implemented to ensure consistent availability of necessary bandwidth, or the remote-control systems needs to be designed to tolerate occasional bandwidth reduction. Considering requirements for test areas for developing autonomous vessels, ensuring sufficient robust connectivity is significant for remote controlled operations.

2.5.2 Autonomous navigation

When moving from remote control towards autonomous operation, the related technical challenges shift from connectivity towards efficient onboard computing. As outlined above, for large-scale automatic scene understanding, a situational awareness system needs to perform sensor fusion, i.e. combine data from multiple high-bandwidth perceptual sensors, and extract and classify features in the obtained data using e.g. deep neural networks. Thus, obtained semantic information can be combined with spatial information from lidar and radar measurements to provide data for mapping, localization, and dynamic route planning. It can be assumed that there is less need to continuously transmit sensor data between the ship and shore when a vessel is in autonomous operation mode, as opposed to remote control mode. It may, for example, be sufficient to transmit only sensor fusion -based object information on the autonomously operating vessel's surroundings, as well as the ship's own location and route plan information.

This high-level situational awareness and route plan information is highly compressed, compared to unprocessed sensor data, with an estimated bandwidth requirement of the order of less than one megabyte per second. Such bandwidth is available through existing maritime satellite connectivity solutions, meaning that from the connectivity perspective, autonomous navigation is feasible globally. However, as discussed above, fallback to remote control may not be possible in areas where e.g. sufficient cellular connectivity is not available.

2.5.3 Logging and Machine Learning

Sensor data needs to be stored in autonomous vessels for multiple reasons, such as to provide a historical log for accident investigations, and to enable system testing, development, and machine learning model training. Especially for ML model training, sensor data should be stored in formats as close to the original sensor outputs as possible, i.e. without significant loss of fidelity. As machine learning model training also requires extensive coverage of possible variations in the modelled data, it is not feasible to collect sensor data on board a vessel indefinitely, and periodical offloading of data is required. Since such data offloading does not need to happen continuously, it is reasonable to perform this using high-speed connectivity when the vessel is at port. The communication bandwidth requirement is then based on the time available at port vs. the logged duration of sensor data to be offloaded.

Table 2 outlines the orders of magnitude of data rates produced by typical autonomous vessel sensors and the data transfer requirements in the operation scenarios considered above. While all these scenarios are feasible with current communication systems, it should be noted that the most suitable technical solutions are different for each scenario. For example, the cases considered here could be implemented using satellite communication systems (autonomous mode), cellular networks (remote control close to shore), and dedicated wide-band communication links (data offloading at port).

2.5.4 Summary of communication scenarios and requirements

Table 2. Example orders of magnitude for uplink data rate requirements in autonomous operation, remote control, and data collection for machine learning and logging.

Sensor	Source data rate (MB/s)	Autonomous navigation (MB/s)	Remote control (MB/s)	Data log offloading (MB/s)*
Cameras (Encoded, 5 visual + 5 thermal)	10	0	10	100
Radar (uncompressed spoke data)	1	0	0	10
Lidar (uncompressed point cloud)	0,1	0	0,1	1
GNSS+INS (uncompressed location/pose)	0,01	0,01	0,01	0,1
AIS (standard messages)	0,001	0	0	0,01
Sensor fusion output (object locations)	0,01	0,01	0,01	0,1
Total order of magnitude	10,00	0,01	10,00	100,00

*** For data log offloading, it is assumed that 1) all sensor and sensor fusion output data is collected and 2) the vessel collects data for 22 h and has 2 h to offload the data when docked**

2.5.5 Cybersecurity concerns

Cybersecurity is a broadly relevant concern for modern software and communication systems, and of course needs to be considered in all developments and deployments of autonomous vessel systems. Specific cybersecurity risks related to the autonomous ship systems outlined in this report include:

1) unauthorized access to vessel remote control systems,
2) unauthorized access to data transmitted from the vessel; acquiring intellectual property without permission,
3) unauthorized access to vessel maintenance systems; tampering with system software,
4) unauthorized access to system development organization and resources; tampering with system software,
5) attacks preventing authorized remote control of the vessel,
6) attacks preventing or spoofing data reception from the vessel,
7) attacks interfering with the operation of the vessel's sensor systems *e.g.* by jamming,
8) attacks spoofing vessel sensors *e.g.* by transmitting false GPS data or AIS messages.

These should be mitigated through a combination of good organizational security practices, use of secure communications, ensuring the physical security of onboard and remote systems, and designing the situational awareness and navigation systems to detect and operate in the presence of external attacks.

2.6 Overview of remote systems

2.6.1 Overview of ML model training and deployment process

The training and testing process for machine learning models used in autonomous vessels is typically a relatively slow process that involves many steps requiring manual labour and various computational operations. Typically training data is collected from sensor systems operating in real environments, storing data either continuously or filtered based on some criteria, such as output from sensor fusion systems on board the vessel, vessel location, or external conditions. However, the training and testing process for the ML model itself does not happen on board the vessels.

Collected sensor data needs to be reviewed and annotated by human observers. Annotation in this context means manually generating metadata that describes in some machine-readable format the contents of the source data. For example, typical annotation data for image-based object detection tasks consists of a list of minimal bounding rectangle coordinates and object type classifications (from a predefined set of possible classes) of all objects present in the image under annotation. Manual data annotation is critical for machine learning, as it is the primary mechanism through which human perception capabilities are transferred to computational models using supervised learning.

As manual annotation is a labour-intensive process, it is commonly performed using crowd sourcing services, where large numbers of workers annotate data examples in parallel, receiving typically compensation per annotated example. Since the performance of a machine learning model is dependent on the quality of data used for training, crowd sourcing -based data annotation can be challenging when developing models for demanding tasks such as distinguishing object classes in domain-specific applications. A randomly selected person may not, for example, be able to reliably identify many types of ships or aids to navigation. Thus, to generate high-quality domain-specific annotation data, it may be necessary to employ domain experts and to manually review the annotations.

Crowd sourcing training data annotation in the ML context also involves potential ethical concerns (Schlagwein, Cecez-Kecmanovic, and Hanckel 2019). Crowd sourcing has been criticized, for example, for providing cheap labour and global arbitrage that circumvents workplace regulations.

Subsequent training of ML models then consists of selecting of training, validation, and test sets from annotated data, pre-processing of the data for ML model training, and selection of model architectures with sufficient complexity to enable representing the characteristics of the training data. In the training process, ML models are adjusted in an iterative process using optimization algorithms to reproduce the characteristics of annotations. Separate validation data sets are needed in the model development process to prevent overfitting, which means that a model learns the desired output for the training data set but does not generalize to other examples. The model training process is also repeated on multiple variants of model architectures to find the most suitable models and optimization procedures – a process called hyperparameter tuning. It is also typical to use a third data set, called test set or holdout set, to evaluate a model when the training and hyperparameter tuning processes are complete. This data set should not be used in the training or validation stages in order to ensure that the model does not overfit to the validation data.

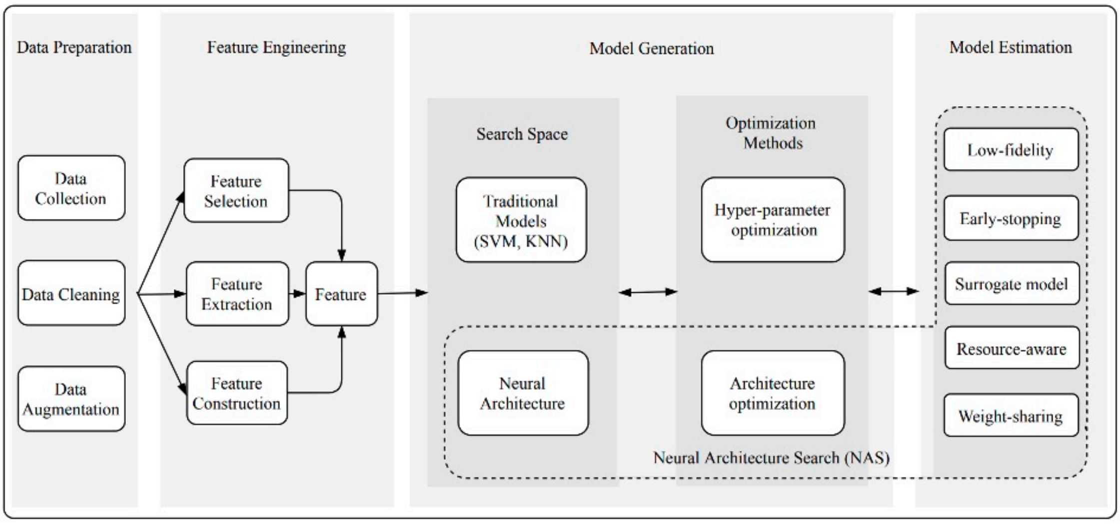

Figure 10. Overview of an AutoML pipeline (Source: He, Zhao, and Chu 2020).

The above described training process involves several manual steps, such as selecting suitable training data, pre-processing operations, model architectures, and parameters to be tuned. These are largely dependent on the expertise of human developers and cannot be fully automated with current models. However, there is much effort in the ML research community to automate the model optimization process, which is sometimes called AutoML. An overview of the current development in the AutoML field is presented e.g. in (He, Zhao, and Chu 2020). Figure 10 illustrates the related sub tasks, corresponding to the development process outlined above.

Once an ML model has been optimized with the selected training data, its performance should be compared to possibly existing previous versions of models used for the same task. This should be done using a baseline data set applicable for both models, in order to ensure that the new training has not decreased the model's performance in some scenarios compared to previous model versions. This is possible even if the model has been trained using the existing model as a starting point (using so called transfer learning), as artificial neural network ML models are prone to catastrophic interference, (Kirkpatrick et al. 2017) meaning that a model trained with new data may lose accuracy for data from previous trainings, if these are not represented in the current training set.

Once a model is found suitable for production, it is typically optimized for deployment. This means selectively reducing model computational complexity to optimize its resource consumption in the deployment system, while maintaining the model's performance as well as possible. Some trade-offs in accuracy vs. computational complexity are typically involved, thus the model should be tested also after computational optimization. If the model performance is still sufficient it can then be transmitted for testing in live systems.

One way of verifying a new model's performance safely in a live environment is to perform A/B testing with the existing model by running both models in parallel, using only the older model version operationally, but collecting the outputs of both models for offline verification. Once found suitable for operation, the new model can enter into service in the system.

2.6.2 Testing and regulation

Considering third party verification or regulation of ML models, with respect to the development process outlined above, several possible approaches can be identified:

1) Verification of the development process and practices used for ML model training and validation (process verification).
2) Verification of the trained, computationally optimized models before allowing updates on board a vessel (simulation testing).
3) Verification of results from live testing of models on board vessels (offline real-world testing).
4) Verification of correct operation of the whole autonomous navigation system after ML models have been updated and taken into use (online real-world testing).

These approaches have distinct benefits and limitations. Process verification is the simplest to implement, as standards, best practices and certifications already are commonly enforced in software development, and would mainly have to be extended to machine learning model development. For example, ISO committee ISO/IEC JTC 1/SC 42 is currently developing the standard ISO/IEC CD 23053.2 - Framework for Artificial Intelligence (AI) Systems Using Machine Learning (ML). However, even correct development processes are not guaranteed to always produce safe and ethically sound results.

Simulation testing, using dedicated test data sets not available to developers or simulated sensor data in a wide range of scenarios, would enable the most accurate verification of the behaviour of models in development. This would require resources, such as data sets, simulation software, and computational capabilities, and a relatively high level of technical expertise. The main challenge in testing with data from real sensors is that the test data needs to sufficiently cover the use cases and scenarios, while a major challenge in simulation testing is to produce sufficiently realistic simulated sensor data, for example, by modelling real camera systems operating in natural environments.

Compared to simulation testing, offline real-world testing reduces the need for maintaining specific data sets or simulation environments for model testing. The models in testing are deployed on real ships parallel to the ship's standard operational control methods, and the data and model outcomes are stored and analysed offline. One trade-off in this approach is that data collection per vessel is relatively slow, and coverage of operational scenarios relevant for testing is not guaranteed. However, these limitations are reduced if the model is deployed for operational data collection to a large number of vessels simultaneously. After the collection, the test data also needs to be separately labelled or annotated for performance verification.

Online real-world testing would in practice mean operational field trials for the entire autonomous navigation system. One benefit in this is that the performance criteria could be specified in terms of conventional navigational requirements, as opposed to setting system sub-component specific statistical requirements, which may be difficult to apply to real-world performance. However, such trials need to be arranged in controlled environments, which is costly, not easily scalable, and does not guarantee coverage of all typical operating conditions. Furthermore, verifying all software or model updates by field trials is not feasible, as modern software development and especially machine learning model development are iterative processes.

It should be noted that all the above described performance verification approaches should be a part of the normal development cycle of autonomous navigation systems. A relevant question for regulation is to which extent third parties should be involved in the performance evaluation. This is mainly a challenge in data-based or simulation-based testing (approaches 2. and 3.), where third party verification would require models to be tested under common performance requirements. It is difficult to set global performance requirements if models are tested by system developers using their own data sets or sea trials, as test results depend on the data sets, simulations, and trials used. In order to enable global performance requirements for subsystems or ML models, it would be necessary to maintain independent third party datasets or simulators for model and system testing from multiple developers. However, this is a technically demanding task due to the wide variety of models and scenarios to be tested.

2.6.3 Sensor system calibration

To ensure safe operation of autonomous navigation systems, it is crucial that the sensor systems used in sensor fusion for situational awareness are correctly measured and calibrated. An especially important calibration task for sensor fusion is accurately measuring the installation locations and orientations of sensors installed on board each vessel. Since it is typically necessary in the marine environment to detect and evaluate the locations of external objects at ranges of up to tens of nautical miles, even minor errors in the estimated orientations of sensors, such as cameras, radars, lidars, or inertial measurement units, may cause significant positioning error and prevent correct sensor fusion.

Sensor calibration measurements need to be performed individually for each vessel, and resulting configuration information needs to be included in the sensor fusion software of the operational system. One relevant aspect for regulation is specification of the level of tolerance for error in sensor calibration information, as this essentially affects the range at which the autonomous vessel can measure its surroundings with given accuracy.

It is possible also to algorithmically test and correct for errors in sensor calibration information on board the vessel, especially if the sensor fusion system contains many sensors and the configuration errors are relatively small. Periodical software-based estimation and correction of sensor calibration error may even be considered a necessary feature for autonomous vessels, as it is possible, depending on the mechanical sensor installations, that sensor alignments change during the operation of the vessel due to external conditions.

2.7 Summary

The main computational tasks in autonomous navigation are maintaining situational awareness of the ego vessel and its surrounding environment, as well as carrying out navigational planning and control based on the situational awareness information. Situational awareness is composed using a variety of sensors, sensor-specific signal processing algorithms, and sensor fusion to combine information from multiple sources.

The main objectives for sensor fusion are to provide comprehensive and accurate information on object types and locations, and to enable redundancy to handle sensor failures or difficult operating conditions. In an autonomous system, it is necessary to assume that any sensor or subsystem may be affected by external conditions or may fail and cannot be immediately replaced. The system should still be able to operate safely despite such sensor limitations or failures. A relevant regulatory concern is to define requirements for autonomous vessels' operation in the presence of sensor failures, difficult environmental conditions, or malicious external influence, such as sensor jamming and spoofing.

In situational awareness, the most significant applications for machine learning models are detecting objects from various sensor data and classifying these objects according to pre-trained categories. Such models provide both robustness for estimating object locations based on multiple sensor inputs, and semantic information on objects, such as types of vessels and aids to navigation. Automating visual watchkeeping, as mandated by current maritime regulations, requires the use of machine learning models, as no conventional rule-based algorithms provide comparable accuracy. In navigational planning, machine learning models can be used for example to predict the future trajectories of other vessels, or to control vessel manoeuvring systems in complex scenarios where basing route plans on explicit rules or conventional optimization algorithms is not feasible. However, in navigational planning, ML models are not strictly required for any critical functionality, and they should be applied in combination with rule-based systems to ensure safe operation.

As machine learning models are applied in the considered systems in a similar way and for similar purposes as conventional signal processing algorithms, they do not present new ethical concerns per se. ML models may be necessary or useful components for automating tasks that currently require human activity, like watchkeeping or navigational planning. However, by nature, the correct performance of ML models cannot be fully guaranteed in all conditions and scenarios, and the difficulty of automating various navigation or watchkeeping tasks may vary greatly. It is therefore relevant for regulation concerning autonomous vessels to specify precisely the requirements for implementing navigational capabilities depending on ML models, as well as the technical performance criteria for such tasks and models.

Autonomous vessels require communication channels for multiple purposes, such as monitoring the location, situational awareness, and route plans of the vessel in autonomous operation, and offloading stored sensor data for algorithm development and data logging. A specific requirement relevant for autonomous vessel test areas is that they provide sufficient communication infrastructure for remote controlled operation. This can be enabled using existing cellular communication network technologies, provided that sufficient bandwidth and availability can be guaranteed in the operational area.

Machine learning models are not trained on board the vessel during operation, but as part of normal system development. A characteristic of machine learning model development that is significant for regulation is that ML models cannot be comprehensively tested using conventional software validation and verification approaches. Validation of autonomous navigation systems containing ML components should consist of a combination of development process standards, statistical model and algorithm testing that uses recorded sensor data sets, system simulations that focus on testing difficult navigation scenarios, and field trials.

Field tests are important for collecting sufficient data sets, enabling the evaluation of practical sensor performance and subsequent ML model behaviours. Government-aided autonomous vessel testbeds and development projects could be beneficial as generators of common test data sets, either open or managed by regulators, which would be valuable in creating common performance requirements and standards for autonomous navigation systems.

3 Regulatory challenges linked to MASS trial areas in the Baltic Sea

3.1 Introduction

This Chapter covers the current legal framework for MASS and analyses to what extent MASS operations may be undertaken in the Baltic Sea area, as well as identifies the main challenges in this regard. The legality of MASS operations - whether permanent or on a trial basis - is determined by several types of laws, depending on the area of the operation and the type of ship involved.

Maritime law consists of a series of regulatory layers and institutions. Different types of issues are handled by different legal sources and institutions. The different layers of law that apply to maritime law more generally are illustrated in Table 3 below.

Table 3. Layers of regulation in maritime law

	Jurisd. rules (main target: flag, coastal and port states)	**Technical req. and standards** (main target: flag states)	**Private law issues** (target: shipowners and commercial partners)	**Other rules** (e.g. criminal, social, commercial, public law)
Global (UN)	UNCLOS			
Global (IMO & ILO)		SOLAS, MARPOL, STCW, COLREGS, MLC		
Global (IMO, UNCITRAL, CMI etc.)			Private law conventions on e.g. liability, limitation, arrest, carriage of goods, salvage, etc.	
European Union		Ship safety directives & regulations Limitations on exemptions	Product liability rules, insurance requirements Rules on competent jurisdiction and applicable law	Several specific issues covered by EU Treaty & legislation (e.g. internal market, competition
Nordic states			Nordic Maritime Codes, Nordic marine insurance terms	
National (Finland)		National implementing legislation, discretion of flag state administration (Traficom)	Finnish Maritime Code 674/1994, other specified acts on contracts, tort liability, insurance etc.	The entire legislation applies a priori for ships flying its flag

At global level, two main categories of rules need to be distinguished. First, there are the jurisdictional rules of the law of the sea, which lay down states' rights and obligations to regulate and take measures with respect to foreign ships in various maritime zones. These are mainly laid down in the 1982 UN Convention on the Law of the Sea (UNCLOS) and are discussed in section 3.2 below. Secondly, the more detailed technical requirements covering safety, navigation, manning and watchkeeping standards for ships etc., are laid down in separate conventions, usually adopted by the International Maritime Organization (IMO). The most important provisions are discussed in section 3.3.

These international rules are then implemented in - and at times supplemented by - national rules, which govern national MASS operations and the implementation of international rules for domestic ships worldwide. The Finnish legal framework, and to some extent the corresponding Norwegian one, are outlined in section 3.4. One of the key instruments involved, the Maritime Code, which mainly addresses private law issues linked to shipping,is developed jointly in the Nordic countries and is very similar Denmark, Norway, Finland and Sweden.

In addition, EU rules regulate maritime safety and some other selected fields of maritime law. However, the existing EU rules do not generally prescribe technical standards for the safety of navigation or ship construction and do not therefore involve limitations on the operation of MASS in the same way as the IMO rules do. There is accordingly less need for rule amendments at EU-level, albeit that some EU rules for specific categories of ships, such as passenger ships in domestic traffic, may need to be scrutinized if the MASS in question belongs to this category. Rather, the EU rules have a potentially supporting role, mostly in the field of data and information exchange. The way in which EU rules and tools could contribute to the development is discussed in section 3.5.

The legal challenges linked to MASS trials are largely identical to those facing permanent (long-term) MASS operations. Therefore, even trials need to comply with the general rules, subject to certain exceptions that have been specifically developed for trials. For this reason, the main part of this section does not distinguish between trials and permanent MASS operation. The application of certain trials exceptions is addressed in the case studies in section 3.6.

Another underlying assumption is that MASS will have to comply with the general legal regime for the type of ship in question. MASS will not therefore be subject to a uniform legal regime, but will be subject to the general rules that apply for passenger ships, cargo ships, bulk carriers etc. of a given size, depending on the type of MASS. Potential standards for MASS will operate on top of those existing rules, and may include exemptions from them, but being categorized as MASS does not affect the duty to comply with rules that would apply to the ship if it was conventionally operated.

It is further assumed that any type of MASS, at all autonomy levels, is potentially an interesting future development. The report does not therefore make any preferences between different solutions for achieving autonomy, and includes gradual developments in the field of autonomy level and manning within its scope.

3.2 UNCLOS

3.2.1 General

The law of the sea deals with the rights and obligations of states over the seas, e.g. the extent to which ships can navigate in different sea areas; the obligations states have over ships flying their flag; and the rights of other states to interfere in the navigation of ships in different sea areas. The 'Constitution for the Oceans', UNCLOS, enjoys a widespread formal acceptance worldwide (168 contracting parties) and its provisions concerning navigational rights and duties are widely accepted as representing customary law (and hence apply to non-parties as well).

Based on the rules for maritime zones of UNCLOS, the Baltic sea is already fully delimited. The entire sea is covered by coastal waters of its 9 littoral states, as illustrated in the map below. For the purpose of MASS, however, this complete coverage is of limited relevance, given that states have little additional jurisdiction over the safety of ships (apart from environmental protection) in the EEZ, as compared to the high seas.

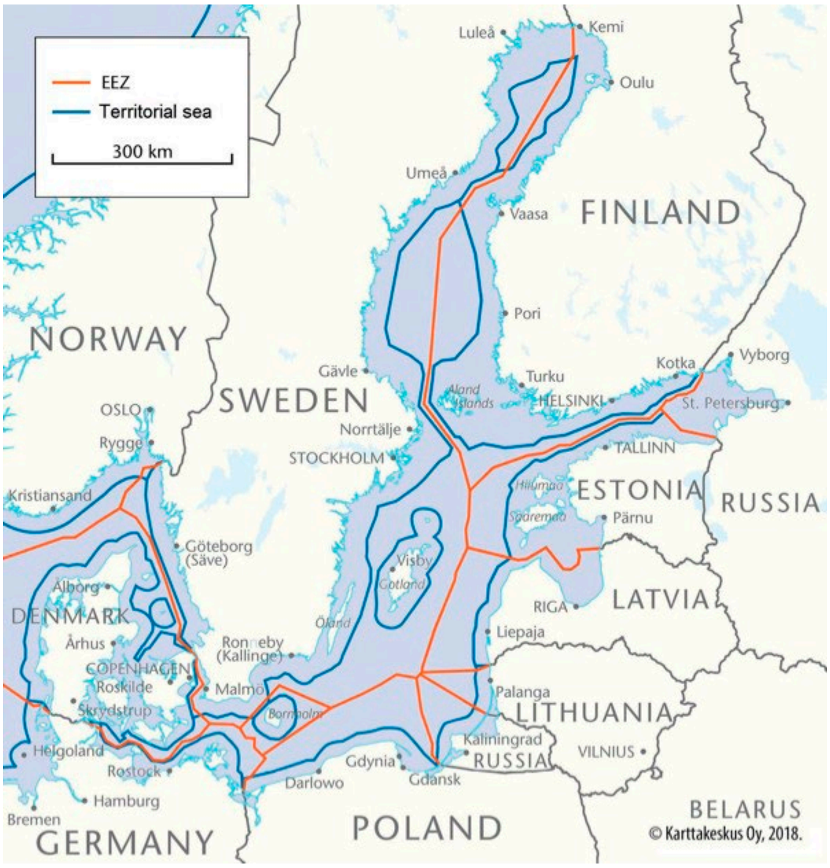

Figure 11. Maritime zones in the Baltic Sea.

Assuming that MASS are considered to be 'ships' or 'vessels' within the meaning of UNCLOS,[3] they are subject to the same rights and obligations under the law of the sea as any ordinarily manned ship. This applies to flag states as well as coastal states, which are briefly discussed separately below.[4]

3.2.2 Flag state jurisdiction

Flag state jurisdiction represents the traditional cornerstone of the regulatory authority over ships. UNCLOS establishes that all states have a right to sail ships flying their flag and to fix the conditions for granting nationality to ships (Articles 90 and 91(1)). However, the convention also includes a number of detailed duties for flag states. Every state has the obligation 'effectively to exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag' (Article 94(1)), including to "assume jurisdiction

3 The two terms are used interchangeably in UNCLOS, but neither is defined. See e.g. Veal & Ringbom, 2017.

4 On this, see also Ringbom 2020.

under its internal law over each ship flying its flag and its master, officers and crew in respect of administrative, technical and social matters concerning the ship" (Article 94(2)(b)). The flag state shall also "take such measures … as are necessary to ensure safety at sea with regard, inter alia, to … the manning of ships, labour conditions and the training of crews, taking into account the applicable international instruments" (Article 94(3)(b)), including measures necessary to ensure "that each ship is in the charge of a master and officers who possess appropriate qualifications, in particular in seamanship, navigation, communications and marine engineering, and that the crew is appropriate in qualification and numbers for the type, size, machinery and equipment of the ship" (Article 94(4)(b)). When adopting these measures each flag state is required "to conform to generally accepted international regulations, procedures and practices and to take any steps which may be necessary to secure their observance" (Article 94(5)).

UNCLOS, in other words, avoids formulating more precise obligations of flag states by referring to an abstract, and continuously changing, set of international rules to be developed elsewhere. In this way, it avoids 'freezing' the requirements at a given point in time or at a given technical level, while still preserving the international character of the rules in question. The more precise extent of flag states' obligations is hence left to be developed by the IMO in particular.[5]

3.2.3 Port and coastal state jurisdiction

While the flag state's jurisdiction applies irrespective of the ship's location, other states' parallel jurisdiction over the same ship depend on the maritime zone concerned. The coastal state's authority over a foreign ship, including MASS, increases with the proximity of the ship to its shores.

3.2.3.1 Internal waters

If a foreign ship is voluntarily present in a state's port or internal waters (inside the baselines from which the limits of the territorial sea are measured, such as in the Archipelago Sea in Finland), the state has broad jurisdiction over the ship. Internal waters form part of the sovereignty of the state (UNCLOS Article 2) and in the absence of specific limitations, the jurisdiction over foreign ships in this area is therefore complete. Moreover, ships have no general right to access foreign ports and the port state's wide discretion to place entry conditions for foreign ships is broadly acknowledged, including in UNCLOS Articles 25(2), 211(3) and 255. In other words, a port state may (unless it has accepted specific obligations to the contrary) refuse MASS access to its ports or internal

5 Veal & Ringbom, 2017, ILA Report, 2000. See also IMO Doc. LEG/MISC.8.

waters, provided that the refusal complies with certain criteria of reasonableness that exist in general international law, such as non-discrimination, proportionality between the measure and its objective and that the prohibition does not constitute an abuse of right (Article 300). This may turn out to be a significant limitation of the freedom of movement of unmanned ships, but the limitation is not unique to MASS.

By contrast, if a coastal state wishes to allow the operation of MASS in its internal waters, whether for trials or more permanently, the complete sovereign jurisdiction means that the coastal state may both permit the operation of (domestic and foreign) MASS in their internal waters and require other ships entering those waters to accept and respect the presence of MASS therein as a condition for entry. A prudent coastal state would have a self-interest to inform other ships in advance about the presence of MASS, and of potential special rules or implications that apply in the areas concerned. If ships of other states were not prepared to accept the perceived risks involved in co-navigating with MASS, they could decide to stay out of such areas, but if they decided to enter, they could not object to the presence of MASS in such waters.

3.2.3.2 Territorial sea

The starting point in the case of territorial sea, which may extend up to 12 nautical miles from the coastline/baseline, is similar to that of internal waters. The territorial sea forms a part of the national territory that the coastal state has sovereignty over. The one major limitation to this starting point is the right of innocent passage that ships of other states enjoy in these waters. Passage is deemed to be innocent, as long as it is not "prejudicial to the peace, good order or security of the coastal state" (Article 19(1)). A list of activities that meet those criteria is given in Article 19(2), which focuses on ships' activities (such as the use or threat of force, military activities, fishing activities or any act of wilful and serious pollution contrary to UNCLOS).

Regarding the coastal state's legislative jurisdiction, Article 21(2) provides that a state may not impose its national requirements on the construction, design, equipment or manning of foreign ships in its territorial sea, unless those requirements are giving effect to "generally accepted international rules and standards". Independently of what laws the coastal state has adopted, it may not "impose requirements on foreign ships which have the practical effect of denying or impairing the right of innocent passage" (Article 24(1)(a)). The right of innocent passage extends to ships that may be deemed to pose a particular risk for the coastal state, such as tankers and nuclear-powered ships and ships carrying nuclear or other inherently dangerous or noxious substances (Articles 22(2) and 23).

It is difficult to see how the presence of MASS in the territorial sea as such could be considered to hamper the right of innocent passage of other ships. That right relates to the use of other states' territorial sea for the sole purpose of navigating through these waters and is subject to a number of qualifications relating to the passage and the innocence thereof (UNCLOS Articles 18 and 19). The presence of MASS in the area would not have the practical effect to deny or impair foreign ships' passage, in particular as locally authorized MASS operations would normally seek to promote the integration of MASS into an environment of traditionally operated ships. Even if certain MASS operations were considered to involve more risks for other ships, it may be noted that coastal states in such cases have a right to temporarily suspend foreign ships' right of innocent passage "in specified areas of its territorial sea ... if such suspension is essential for the protection of its security." (Article 25(3)) Moreover, the right of innocent passage does not include a right to choose any route in other states' territorial sea. Coastal states have specific powers to require foreign ships to use "such sea lanes and traffic separation schemes as it may designate or prescribe for the regulation of the passage of ships," and "where necessary having regard to the safety of navigation" (Article 22(1)).

Ships exercising their right of innocent passage must comply with coastal states' laws and regulations on, inter alia, "the safety of navigation and the regulation of maritime traffic" and with "all generally accepted international regulations relating to the prevention of collisions at sea." (Article 21) The latter quote suggests that any MASS operating in the territorial sea shall operate by the same collision avoidance rules as other ships. This also follows from the geographical scope of applicability of the COLREGs (Rule 1a).

Under UNCLOS Article 24(2) the coastal state shall "give appropriate publicity to any danger to navigation, of which it has knowledge, within its territorial sea," which at least in the early phases of MASS probably must be understood as a duty to inform other ships of the presence of MASS in the area.

In conclusion, international law of the sea supports the proposition that the operation of (national and foreign) MASS may be authorized by a coastal state in its territorial sea as part of its territorial sovereignty, as long as the right of innocent passage of other foreign ships is not "hampered" and subject to the requirements relating to notification, publicity and other precautionary requirements that are included in various parts of UNCLOS Part II, section 3.

3.2.3.3 Exclusive economic zone/High seas

The jurisdiction to prescribe national requirements is even more limited with respect to ships sailing in the exclusive economic zone (EEZ), which may extend beyond the territorial sea, up to a maximum of 200 nm from the coastline/baseline. In this maritime zone, freedom of navigation applies, but is limited to the extent that coastal states have been granted jurisdiction over specified matters. The rights and jurisdiction provided to coastal states do not extend to maritime safety, insofar as it does not relate to the protection and preservation of the marine environment (Article 56(1)), while the flag state freedoms, including the freedom of navigation specifically apply (Article 58(2)). In the EEZ, flag states and coastal states must operate with due regard for the interests of each other (Articles 56(2) and 58(3)), but there is no provision to suggest powers for the coastal state to authorize MASS to navigate in their EEZ, if the MASS does not comply with international safety standards.

The regulation of MASS by coastal states on the high seas is obviously even more difficult. Here, the starting point is that the flag state alone has jurisdiction over the ship. A flag state's jurisdiction over its ships is in principle exclusive "save in exceptional cases expressly provided for in international treaties and [UNCLOS]" (Article 92(1)). A number of exemptions to this main rule exist, but none of them is relevant for the question of navigational rights of unmanned or autonomous ships and no high seas areas exist in the Baltic Sea.

3.2.4 Conclusion

In conclusion, flag states' abilities to authorize MASS depends more on IMO rules and national policies than on the rules of UNCLOS. States seeking to implement trials may do so within their own territorial borders (internal waters and territorial sea). They may also organize MASS operations in their internal waters and territorial sea to the extent that it does not hamper other ships' right of innocent passage. Beyond that, in the EEZ and high seas, the starting point is freedom of navigation, but also that all flag states comply with the applicable international standards.

Other states may choose not to permit (foreign) MASS into their internal waters and ports. Their right to refuse the passage rights of MASS in their territorial sea is more limited and depends on the on the extent to which the MASS in question complies with the IMO rules, as well as the perceived threat of the MASS. In the EEZ, the jurisdiction of coastal states to interfere with MASS in their coastal waters is limited to environmental concerns and is therefore unlikely to be relevant.

3.3 IMO rules (selection)

3.3.1 General

There are over 50 IMO international shipping conventions in force today. The majority of the obligations set out by IMO regulations are imposed on flag states, which in turn have to meet their international obligations by prescribing enforceable domestic legislation reflecting the international standards. The target of these obligations is usually the shipowner, who cannot be directly subject to obligations under international law. States often delegate the tasks of enforcement of the domestic regulations to expert governmental maritime administrations or authorities.

Generally speaking, the IMO requirements are set as functions to be performed and are usually neutral as to the method by which they are met. Most of the relevant rules have been developed many decades ago, at a time when unmanned or autonomous operations were not conceivable. Consequently, the rules do not normally require ships' crews to be on board, as their presence is assumed. Relatively few of the existing rules therefore positively prohibit MASS.[6] The more typical scenario is that the IMO rules do not directly rule out MASS operations, but need to be understood or interpreted in a particular way in order to permit autonomous or unmanned operations. Such interpretations involve all parties to the conventions in question and cannot therefore be done separately by individual parties (flag states). The conventions that give rise to most legal questions, and which will therefore be in focus here, are (selected parts of) the International Convention for the Safety of Life at Sea 1974 (SOLAS), the International Regulations for the Preventing of Collisions at Sea 1972 (COLREGS) and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention), as amended. A more detailed review of the full breadth of IMO conventions is currently undertaken by the IMO in the context of the 'Regulatory Scoping Exercise'.[7]

3.3.2 SOLAS

3.3.2.1 Chapter I General provisions

SOLAS applies to MASS to the extent that they engage on international voyages.[8] The Convention prescribes no general definition of 'ship' and so MASS operations presents no obstacle to applicability. Instead, SOLAS refers to 'cargo ships', defined broadly as any ship which is not a passenger ship, i.e. a ship certified to carry less than 12 passengers.[9] However, the Convention does not apply to ships of less than 500 gross registered tons (grt), although this is subject to the specific applicability provisions in each chapter.[10] The

6 A number of studies have been carried out on the topic in the past few years and the results tend to be fairly uniform. See e.g., CMI study (MSC 99/INF.8); Danish study (MSC 99/INF.3). For a compilation of relevant studies by the IMO Secretariat, see IMO Doc. MSC 100/INF.3.

7 See e.g. IMO Doc MSC 102/5 and related documents. This section is largely based on the analysis in Veal & Ringbom 2017.

8 'International voyage' is defined in Regulation 2(d) as a 'voyage from a country to which [SOLAS] applies to a port outside such a country, or conversely'. Some parts of the convention, including notably Chapter V, however applies to any voyages.

9 Regulation 2(g).

10 Regulation 3(a)(2).

Annex of SOLAS includes 17 chapters of which the first seven will be briefly considered here.

3.3.2.2 Chapter II-1: Construction

Chapter II-1 deals with ships' structure, subdivision and stability, machinery and electrical installations. Ship structural requirements do not, in general, present particular difficulty for unmanned operation. The chapter does, however, include requirements which necessitate considerations of equivalence in a MASS context. For example, there is the regulation 5-1 requirement that the ship's 'master … be supplied with information … as is necessary to enable him by rapid … processes to obtain accurate guidance as to the stability of the ship under varying operating conditions'. In the case of remote operation, this information must presumably be supplied to remote controllers. In case of fully automated ships, where no person is immediately in charge of the ship's operation, other solutions will be needed for the handling of such information.

Similarly, whenever alarms designed to alert those in command of the relevant ship are required,[11] the spirit of such rules requires alarms to similarly alert those controlling the ship from a remote location. The spirit of such a regulation also requires autonomous ships to be capable of being brought under the immediate control of a remote controller so that someone may act on the alarm signal.

Regulation 55 permits alternative design and arrangements in respect of machinery and electrical installations, subject to the prescribed evaluation and approval.[12]

3.3.2.3 Chapter II-2: Fire protection, fire detection and fire extinction

Chapter II-2 also includes structural requirements but with the specific aim of safety from fire giving detailed requirements for fire detection through appropriate alarm systems (Regulation 7). Regulations 15 and 16 concern onboard training and drills and operations. They are aimed at ensuring that the personnel charged with command of the ship are prepared in the event of fire to combat and contain it. This presents challenges of equivalence in the context of an entirely shore-based crew. While strict application of the chapter presents difficulty for unmanned operations, regulation 4(1) gives the relevant maritime administration the ability to exempt individual ships from the requirements of the chapter if its full application is deemed 'unnecessary or unreasonable', provided

11 Regulation 38. See also Regulations 51 and 53(4).

12 See also the Guidelines on alternative design and arrangements for SOLAS chapters II-1 and III (MSC.1/Circ.1212) and the Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments (MSC.1/Circ.1455).

that the relevant ship is not to exceed a distance of 20 miles from the nearest land. This dispensation will be important since arguably much of the spirit of the chapter is aimed at the preservation of onboard personnel and/or passengers from fire, potentially lacking application in some MASS operations. This is an issue which must be addressed by those developing the technology for unmanned shipping, as well as regulators. The use of alternative design and arrangements is also permitted after the necessary evaluation and approval (Regulation 17).

3.3.2.4 Chapter III: Life-saving appliances and arrangements

Chapter III prescribes the life-saving appliances to be carried on board the relevant ship and corresponding arrangements. It contains the same general exemption as Chapter II-2 (Regulation 2). The chapter prescribes standards for onboard operations, such as maintenance (Regulation 36). Here too, consideration will be required as to its necessity and feasibility with regard to MASS. In the context of the carriage of passengers, however, passenger safety must be ensured to the same extent whether the ship is manned or unmanned. Some important requirements are, for instance, in the context of survival craft. Regulation 10 requires that: "there shall be sufficient crew members, who may be deck officers or certified persons on board for operating the survival craft and launching arrangements". Whilst the chapter permits the use of alternative design and arrangements, (Regulation 38) it will be very difficult for an UCMASS carrying passengers to comply with this regulation without posting onboard personnel trained in evacuation procedures.

3.3.2.5 Chapter IV: Radiocommunications

Chapter IV deals with radiocommunications and prescribes functional requirements for ships in the form of transmission capability. The chapter is exceptional in that it expressly applies to cargo ships of 300 grt upwards (Regulation 1). The chapter requires continuous watches to be kept on prescribed channels (Regulation 12). Regulation 16 expressly requires that every ship "carr[ies] personnel qualified for distress and safety radiocommunications". This regulation presents difficulty for unmanned ships. From an equivalence standpoint, it is essential that the prescribed radiocommunications capabilities may be discharged remotely. Again, the adequacy of any such arrangement will be subject to the satisfaction of the relevant maritime administration. Be it on board or shore-based, the essence of the chapter speaks of human oversight. This presents acute difficulty for AO-MASS.

3.3.2.6 Chapter V Safety of Navigation

Chapter V applies to all ships on all voyages, but flag states may exempt most of the chapter's requirements for ships below 150gt in international voyages or 500 on domestic voyages.[13]

For the purposes of MASS, the most important regulation in Chapter V is arguably Regulation 14 on ships' manning, which only applies to ships on international voyages.[14] It requires contracting governments to adopt measures to ensure that: "from the point of view of safety of life at sea, all ships [are] sufficiently and efficiently manned". The relevant maritime administration must establish appropriate minimum safe manning following a transparent procedure, and issue an appropriate minimum safe manning document as evidence of the minimum manning considered necessary. This is achieved not by providing a certain minimum number of crew, but by listing in the associated guidelines on safe manning a series of functions that need to be performed by the ship's crew.[15] The guidelines are generally formulated by means of goals to be achieved, which opens the door for both remote and autonomous operations. Indeed, the guidelines specifically provide that the technical equipment and level of automation are to be taken into consideration when deciding on manning levels.[16] The adequacy of manning arrangements is a concept relative to the particular ship in question, and its particular capabilities. Strictly speaking, neither Regulation V/14 itself, nor the guidelines to which it refers, rule out that a flag state decides that the safe manning level for a particular MASS can be set at zero. However, a clarification of this matter would certainly seem desirable before flag states start issuing such manning certificates. Gaining the approval of maritime administrations may prove difficult, particularly in the early phases of MASS and in the absence of regulations or common principles for these particular operations.

Regulation 33 reiterates the obligation for the master of a ship, if in a position to do so, to proceed with all speed to the assistance of persons in distress at sea. For the duty to be of any relevance in an unmanned context, a member of the shore-side personnel controlling or supervising both remote controlled and autonomous ships must be deemed to be the unmanned ship's 'master'. The obligation is not confined to taking persons on board. In an unmanned context the duty may be discharged by ensuring that any distress signals received are relayed to the relevant search and rescue authorities or by retaining a proximate position to form a hub for communications. The requirement is determined by

13 Regulation V/1(4)

14 Regulation V/14 refers to the applicability of Chapter I which, as a starting point, covers passenger ships of any size and cargo ships above 500gt on international voyages.

15 IMO Resolution A.1047(27).

16 IMO Resolution A.1047(27), Annex 2, paras. 1.1.3, 1.1.4 and 1.1.10. Veal et al 2016, p. 49, conclude that a flag state may "consider manning requirements to be significantly reduced, non-existent or replaced by shore-based controllers." See also Skjong, p. 5.

the reasonable capabilities and limitations of the ship .[17] On balance, if a remote controller of a MASS were to discover people in distress and does nothing at all to endure that the appropriate authorities are informed, he would be in breach of the duty.

Importantly, Regulation 3 (Exemptions and Equivalents) provides that maritime administrations may grant exemptions and equivalents when an absence of general navigational hazards and 'other conditions affecting safety' are such to render a full application of Chapter V 'unreasonable or unnecessary'. Specifically cited conditions are the duration of the voyage and the maximum distance of the ship from the shore. The extent to which a MASS may rely on this flexibility will depend on its itinerary. Again, much may depend on the ability of a potential unmanned ship operator to convince the relevant authorities as to the safety of the alternative means by which the vessel will be navigated, be it remotely or autonomously.

3.3.2.7 Exceptions

SOLAS is not without flexibility. A contracting government may exempt ships which 'embod[y] features of a novel kind' from compliance with the provisions in Chapters II-1, II-2, III and IV, to the extent that the application of such provisions 'might seriously impede research into the development of such features and their incorporation in ships engaged on international voyages'. It can be argued that remote control and autonomous operation constitutes a feature of a novel kind, and therefore such ships may stand to benefit from this dispensation. Much may depend on the flag state administration's attitude towards the technology. Further possibilities for the contracting government to grant exceptions to individual ships from the requirements of certain regulations are set out in the respective chapters. There are also considerable available 'equivalents'. When a SOLAS provision calls for a 'particular fitting, material, appliance or apparatus, or type thereof, [to] be fitted or carried in a ship, or any particular provision [to] be made', the relevant maritime administration may permit the use of alternatives to be carried if it is satisfied that these are at least as effective as the express provisions SOLAS prescribes. It is doubtful that this would permit unmanned operability (to the extent that it is otherwise proscribed) since the ship's crew which, of course, is traditionally on board, cannot be understood to be a 'fitting, material, appliance or apparatus'.

The more operationally oriented requirements relating to safety of navigation in Chapter V are not as flexible, but even here the focus is on functions, and the chapter is mostly

17 Under UNCLOS article 98, the master's duty to render assistance is qualified by the requirement that he can do so 'without serious danger to the ship, the crew or the passengers'. The specific requirement 'to proceed with all possible speed to the rescue of persons in distress' is qualified by the condition that he does so 'in so far as such action may reasonably be expected of him'.

neutral when it comes to technical solutions. As was noted above, Regulation 3 provides some specific possibilities for exemptions and equivalents.

3.3.2.8 Certificates

As a starting point, the right to issue certificates for the ship is limited to the flag state.[18] Apart from this, SOLAS Regulation I/17 provides that:

> *"Certificates issued under the authority of a Contracting Government shall be accepted by the other Contracting Governments for all purposes covered by the present Convention. They shall be regarded by the other Contracting Governments as having the same force as certificates issued by them."*[19]

However, this does not mean that other states need to accept the certificates at face value. In respect of port state control, it is provided that initial checks should be limited to verifying the validity of the certificate, and that more detailed inspections only should be undertaken where there are "clear and unless there are clear grounds for believing that the condition of the ship or of its equipment does not correspond substantially with the particulars" of the certificate. (Regulation I/19(b))

In the case of MASS, the issue is not about non-compliance with the certificate, but with the validity of the certificate as such, and the interpretation of and/or deviations from the SOLAS rules that it represents. This matter is not clearly addressed in the IMO conventions, but it is submitted that Regulation I/17, quoted above, does not amount to a duty for other states to endorse the exemptions or equivalences that the flag state has accepted for a particular ship. A certificate issued by a flag state does not override other states' rights to deny foreign ships navigational rights under the law of the sea. An unmanned ship carrying a safe manning certificate accepting zero crew members on board, for example, may thus very well be denied entry to other states ports, on the basis of the law of the sea. The matter is more complex in the case of passage rights through coastal waters,, but, as noted above, coastal states should not deny passage, excluding in case of well-defined exceptions in UNCLOS or, in some cases, in the IMO conventions themselves.[20]

18 SOLAS Regulations I/12(a)(viii) and I/13.

19 Also MARPOL Article 5(1).

20 See notably STCW Regulation I/13, discussed below. See also Smeele 2020.

3.3.3 COLREGs

The International Regulations for Preventing Collisions at Sea (COLREGs) set out the navigational rules to be followed by vessels with the aim of avoiding collisions. The COLREGs are divided into five parts: Part A sets out general provisions for applicability; Part B prescribes the detailed steering and sailing rules; Part C sets out requirements for lights and shapes; Part D prescribes sound and light signalling requirements; and Part E prescribes select exemptions from the Rules.

Rule 2 is arguably the most important provision in the COLREGs. It provides that: 'nothing in [the] Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any … neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case'. The rule reaffirms the importance of good seamanship over and above a strict compliance with the Rules' steering rules and expressly states that in select circumstances, deviation from the Rules is mandatory.[21] The Rule requires contemporaneous human judgment in the decision-making loop. In principle, this judgment may be provided remotely, subject to the sophistication of the relevant communications technology. Even autonomous ships under permanent supervision paired with an ability to assume remote control arguably satisfy this requirement. Autonomous ships that are unsupervised, however, would have difficulties in meeting Rule 2 in its current form.[22]

Rule 5 requires that: "every vessel … at all times [maintains] a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances … to make a full appraisal of the situation and risk of collision". Reference to 'sight and hearing' clearly requires a human input in surveying and assessing the situation and collision risk, which is consistent with Rule 2. As such, autonomous ships relying, for instance, solely on data processing from camera sensors and radar, as well as control algorithms would not satisfy the requirement of appraisal by sight and hearing. Of course, one might envisage a future of exclusively autonomous ships all communicating with each other so as to prevent close quarters situations. In such a case, the breach of Rule 5 would only be technical, but a breach no less. Even in such a case it can be argued that the currently prescribed human element would provide an essential back-up to an autonomous network. The present generation of unmanned craft use sophisticated aural and camera sensors to project the vessel's vicinity to a shore-based remote controller. This arguably satisfies the Rule 5 requirement with the requisite human input still firmly in the appraisal process in the sense that the use of electronic aids does not take the arrangement outside of the spirit or wording of Rule 5. This is a point which must, however, be clarified.

21 E.g. Veal & Tsimplis 2017, p. 324.

22 Veal, Tsimplis and Serdy, 2019, p. 38. See also Komianos, 2018.

Under Rule 6 vessels must at all times "proceed at a safe speed so that [they] can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions". This is a corollary of Rules 2 and 5, and any foreseeable delay in communications should be factored into the safe speed calculation. The transfer of data to the shore-based remote controller and transfer of orders back to the vessel will inevitably involve a delay of some duration, as will any satellite communications. The same can be said of Rule 8, which requires that any action taken to avoid collision 'shall be taken in accordance with the Rules of this Part and shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship'. The remainder of Part B prescribes the detailed steering and sailing directions to be observed. The key point is that compliance with these provisions presents no difficulty if the relevant unmanned ship has the situational awareness required, in particular, as set out in Rules 2 and 5. As stated above, the required human appraisal arguably is satisfied in the context of remote controlled operation and even supervised autonomous operation so long as there is an ability to assume remote control immediately. Autonomous ships, which are unsupervised, however, cannot meet the requirement.

3.3.4 STCW

The main purpose of the 1978 STCW Convention, as amended in 1995 and 2010, is to establish international standards of training, certification and watchkeeping for seafarers. Through Article III, the Convention expressly applies to "seafarers serving on board seagoing ships entitled to fly the flag of a Party". Arguably, therefore, the Convention does not apply to MASS with no seafarers on board at all, but it does apply to partially manned ships.[23]

The most problematic part of the STCW in relation to MASS lies in the Convention's watchkeeping standards, provided in Chapter VIII and related (mandatory) Chapter A-VIII of the STCW Code, which includes detailed provisions for watchkeeping in various conditions, including requirements on lookout, bridge, engine room and radio watches. Provisions for work hours and resting hours are also included, as well as an obligation to perform route planning ahead of the intended voyage. These requirements cover the key

23 Komianos 2018, p.341.

functions of navigational and engine watches on board ships, and is among the few IMO requirements that specifically calls for the physical presence of seafarers.[24]

Part 4, paragraph 10 (Watchkeeping at Sea) states that: "when deciding the composition of the watch on the bridge the following factors, inter alia, shall be taken into account". One of such listed factors includes: "at no time shall the bridge be left unattended". In addition, paragraph 24 provides 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". To the extent that the STCW Convention applies, these provisions present difficulty for all MASS that involve a (periodically) unattended bridge. It is one of the rare instances of a regulatory conflict with existing IMO rules. It affects all types of MASS (whether remotely or autonomously operated), which needs to be resolved before MASS operations can be authorised.

The rigidity of the watchkeeping requirements is further emphasized by the relative absence of flexibility in their implementation. In contrast to the parts of the STCW Convention that address training and education, the STCW Convention offers no flexibility for flag states to adopt equivalent solutions when it comes to watchkeeping. The only applicable exemption in Regulation I/13 relates to the conduct of trials. This exemption could allow for trials with respect to unmanned bridge operations, presuming that guidelines are adopted by the IMO for the purpose. However, Regulation I/13 includes a number of conditions that are difficult to apply to trials intended to alter manning principles on a more permanent basis. Moreover, para. 7 of Regulation I/13 offers states the option of objecting to the trials, and indirectly offers them the opportunity of barring ships participating in the trials from doing so "while navigating in [their] waters." This contrasts with the freedom of navigation that all ships enjoy in the EEZ of other states and with the right of innocent passage in territorial waters that normally applies to ships performing trials under IMO conventions.

The other key elements of the STCW Convention, training and certification, will not be discussed in detail here. While it is true that MASS introduces into the maritime domain an entirely new set of skills required by seafarers, which are currently not part of the international regime, it is considered that the existing regime can serve as a basis for the training and certification of MASS seafarers. A harmonized training regime needs to be agreed if or when MASS is widespread. Until such specific rules are agreed, it seems

24 STCW Regulation VIII/2.2.1 Administrations shall require the master of every ship to ensure that "officers in charge of the navigational watch are responsible for navigating the ship safely during their periods of duty, when they shall be physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times". Similarly, under Regulation VIII/2.2.3 officers in charge of an engineering watch "shall be immediately available and on call to attend the machinery spaces and, when required, shall be physically present in the machinery space during their periods of responsibility" (emphases added).

reasonable to apply the existing STCW requirements to MASS seafarers, possibly coupled with additional training requirements. In this sense, MASS is not inherently different from other special categories of ships subject to special training requirements.

3.3.5 Conclusion

Even before the IMO's regulatory scoping exercise is concluded, it is possible to make some assessment regarding the scale and nature of the challenge that MASS poses for existing rules, at least in broad terms.[25] One of the few examples of a direct conflict are the watchkeeping provisions of the STCW Convention mentioned above. It is simply not possible to comply with the requirements of physical presence on the bridge at all times, if the functions of the watchkeeping officer are performed remotely or replaced by technology.

The more typical scenario is that numerous IMO rules do not directly conflict with autonomous ships, but need to be understood or interpreted in a particular way in order to permit autonomous or unmanned operations. Such interpretations involve all parties to the conventions in question and cannot therefore be done separately by individual parties (flag states).

SOLAS provides considerable flexibility for flag states when it comes to technical standards. It provides a broad discretion for flag states to approve equivalent solutions and exemptions to the technical requirements in SOLAS Chapters II-IV, provided the flag state is satisfied that the safety level is not compromised. The more operationally oriented requirements relating to safety of navigation in Chapter V are not as flexible, but even here the focus on functions and the chapter is mostly neutral when it comes to technical solutions. Even the crucial Regulation V/14, dealing with the safe manning of ships, only provides that all ships "shall be sufficiently and efficiently manned", opening up for technical solutions to replace functions earlier performed by humans on board.

A related issue that requires legal confirmation, at least in the form of a uniform interpretation, is whether the functions required by the IMO rules (such as e.g. control, monitoring and management functions) can be performed from a different location than on board the ship itself. Can, for example, the master of a ship be located on shore? If so, can the master be in charge of several ships at the same time? Such questions are horizontal in the sense that they apply to many different IMO conventions and their clarification would accordingly resolve a large number of the identified legal challenges.

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25 A number of studies have been carried out on the topic in the past few years and the results tend to be fairly uniform. See e.g., CMI study (MSC 99/INF.8); Danish study (MSC 99/INF.3). For a compilation of relevant studies by the IMO Secretariat, see IMO Doc. MSC 100/INF.3.

A review of the main IMO conventions also reveals that questions regarding the meaning or utility of several rules will be raised, in particular if there are no crew members on board the ship. Examples include access or evacuation requirements, rules on accommodation spaces, and crew drills, etc. All these rules require some form of common understanding on how they are to be understood and applied in the absence of any crew members on board.

3.3.6 New Rules

Reviewing the legal hurdles only in relation to existing IMO rules is insufficient for providing a full picture of the nature of the regulatory challenge posed by the introduction of MASS. The most difficult aspects of the challenge relate to new features, which have not been regulated before. MASS represents a new development and involves many issues that IMO has never had to regulate before.

Most importantly, there are no existing rules on the gathering of situational awareness information by technological means. Independent of whether the development will be towards remotely operated ships or autonomous ships, the current lookout requirements, which are based on human functions, notably 'sight and hearing', need to be adjusted to new forms of technology on board, such as cameras, various forms of radars, acoustic sensors, etc. While there are some precedents in this field,[26] IMO has not yet had to deal with a situation in which the entire lookout function is delivered (and processed) electronically. This future prospect raises new questions on, inter alia, the performance requirements for the sensors and the data processing equipment, the independence and hierarchy between different technologies employed, the principles governing the integration of data, redundancy requirements, and monitoring and oversight tools.

A second category of issues that need to be regulated concerns the relocation of functions from the ship/bridge to a remote location. Remote control is not, strictly speaking, about autonomy, but is in practice closely linked to the development of MASS. Apart from resolving the issues linked to physical presence on the bridge, remote operation requires certain minimum technical standards on the communication between ship and shore, including requirements on communication technology, data transmission capacity, and cyber-security. Moreover, since delays or breakdowns in data transmission are perfectly foreseeable, remotely operated ships with no crew on board also need to have arrangements with respect to their (autonomous) back-up functions to operate, or at least to place themselves into a 'Fail to Safe'-mode, involving minimum risks for the MASS

26 The limited possibilities to detect sounds on board ships with enclosed bridges has later been compensated by a requirement to have a technical device on board to identify sounds and their direction in SOLAS Regulation V/19(2.1.8).

and others, until communication is restored. Third, the most significant aspect of the shift towards autonomy as a matter of principle is the acceptance that technology may replace human operational decision-making. If pre-programmed software and algorithms are to be accepted as alternatives to crew-based decision making, and allowed to be in charge of the operation of the ship even only momentarily, some standards will be needed regarding the underlying 'intelligence' software, acceptable safety margins, and the conditions for operating such systems. Possibly, as will be discussed in Chapter 4 below, automated decision-making will even give rise to a need to regulate the distribution of responsibility between the persons involved in their development, integration and application, as this group extends well beyond persons traditionally associated with the operation of ships.

All three examples relate to completely new regulatory challenges for the IMO, which can hardly be left unregulated at the international level if MASS are to be introduced in a safe and harmonized fashion. New rules on these matters should probably be more flexible and goal-oriented than current prescriptive requirements for ships. Yet, even goal-based standards need some careful regulation concerning the goals to be achieved and the more detailed functional requirements, as well as criteria required for achieving those goals. That regulatory challenge will not be resolved or even understood by only analysing existing conventions, but will need rules to be developed from the offset. These longer-term matters are discussed in more detail in Chapter 4 below.

However, a very first step has recently been taken towards permitting MASS to operate in international waters, through the adoption in June 2019 of Interim Guidelines for MASS trials. Even if in the form of interim guidelines only, this instrument could nevertheless represent the first step towards authorizing MASS to operate internationally on a trial basis.

3.3.7 MASS Trials Guidelines

A first development towards authorizing MASS at international level was the adoption in June 2019 of Interim Guidelines for MASS Trials to assist authorities and stakeholders with ensuring that trials of MASS "are conducted safely, securely and with due regard for the protection of the environment."[27] After a very hectic drafting process, essentially only a few days, the MSC approved a document, which was very different from the one originally proposed by Norway.[28]

27 IMO Doc. MSC 101/WP.8, Annex 3. Subsequently adopted as IMO Circular MSC.1/Circ. 1604.

28 The original Norwegian submission was in IMO Doc. MSC 100/5/2. For the drafting process, see Jungblut 2020, pp. 12-14.

The Interim Guidelines include no geographical delimitation of the area where such trials may take place, indicating that they may be conducted both on ships engaged on international routes and on the high seas.[29] The term 'trial' is defined as an experiment or series of experiments, conducted over a limited period in order to evaluate alternative methods of performing specific functions or satisfying regulatory requirements prescribed by various IMO instruments, which would provide at least the same degree of safety, security and protection of the environment as provided by those instruments.[30]

The definition highlights the temporary nature of the trials, but offers no guidance as to their maximum duration. Trials are closely tied to existing IMO instruments. Their stated purpose is to assess alternative methods to comply with IMO rules and the aim is to find mechanisms to ensure at least an equivalent level of safety. That aim suggests that all IMO standards cannot be complied with during the trial. Accordingly, the Interim Guidelines fall short of requiring full compliance with every provision of the IMO instruments. In paragraph 2.2.1 it is provided that "[c]ompliance with the intent of mandatory instruments should be ensured," while paragraph 2.3.1 similarly holds that "[a]ppropriate steps should be taken to ensure that the intent of minimum manning requirements is met" (emphases added).[31]

Arguably, the main intent of international watchkeeping and lookout rules is to ensure safe operations of ships at all times, and the requirements of physical presence by humans are only means to that end. If equivalent safety can be ensured by other means, the implication is that trials may be approved even if MASS do not comply with some of the current STCW and COLREGs requirements during the trials.

The interests of other parties who may be concerned by the trials are mainly addressed in the form of prior information and notification. Under paragraph 2.6 of the Interim Guidelines "[r]easonable steps should be taken to ensure that potentially impacted third parties are informed of the trial of MASS systems and infrastructure," while paragraph 2.8.1 provides that "[d]etails of trials should be reported to the relevant authorities, as appropriate, as early as practicable, so as to enable the dissemination of information on the trials to all impacted parties in the specified area." The Interim Guidelines also require strategies to be developed for each trial to "mitigate the effects of incidents and/or failure

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29 This is also supported by para. 1.2.3, providing that "[i]t is the responsibility of the flag State Administration to authorize a ship to participate in a trial. Where necessary, authorization should also be obtained from the coastal State and/or port State authority where the trial will be conducted." The role of coastal States is thus left very unclear, but based on the jurisdictional analysis above, their authorization seems necessary at least if trials are to be carried out in their internal waters and probably in their territorial sea.

30 Id., para. 1.2.2.

31 Veal, 2019, p. 3, observes that the meaning of the 'intent' is uncertain, as well as "exactly how this may be deduced and how narrow or specifically" it should be done from the mandatory instruments.

of systems, technology and testing" which "should include the ability to respond to emergencies." In this respect, it is further provided that "[i]nformation related to the ship's performance and the basis of judgement by automated systems should be available to any personnel involved in MASS trials, whether remote or on board."

The legal significance of the Interim Guidelines is uncertain, notably regarding whether they can serve to legitimize MASS operations beyond the national waters of states. On the one hand, the Interim Guidelines, adopted in the form of a circular by the IMO's Maritime Safety Committee, represent a very low key 'soft law' instrument with no legal force per se. Clearly, international legally binding rules cannot be set aside or amended by the Interim Guidelines.

On the other hand, the Interim Guidelines clearly represent, on behalf of the international maritime community, an endorsement that trials may be carried out under certain conditions, and that those conditions neither confine the trials to national waters nor involve full compliance with existing IMO rules. It was further noted above that even non-legally binding rules may form part of the 'generally accepted international rules and standards' referred to in UNCLOS and hence entail legal implications as the minimum standard for flag states and maximum standard of coastal state regulation.[32] Trials conducted on the basis of the Interim Guidelines will thus strengthen flag states' arguments that they are acting in compliance with generally accepted international rules and standards. Conversely, the basis for other states to claim that the trial is not in compliance with IMO rules will be correspondingly reduced.

Whether that can be taken as far as meaning that the parties to individual IMO conventions have agreed to trials involving diversions from their provisions (e.g. by temporarily removing physical presence on the ship's bridge), as long as the 'intent' of those rules is ensured, is doubtful. So far, the Interim Guidelines have not been used for such purposes. Under Article 31(3) of the Vienna Convention on the Law of Treaties, subsequent agreements and practice, including in the form of resolutions or guidelines, can be taken into account in interpreting treaties, but contradicting a treaty's wording goes beyond interpretation.

A particularly interesting example relates to the STCW Convention. It was noted above that the Convention, Annex, Chapter I, Regulation I/13, may open up for MASS trials. While the negotiating history of that provision points to earlier experiments with a single person

32 ILA, 2000.

on watch in hours of darkness,[33] there is nothing in the provision that would exclude the Interim Guidelines for MASS trials from its scope.

Since the IMO has adopted these Interim Guidelines, flag states wanting to conduct trials could argue that they are following this provision and, thus, are lawful, as long as the other states parties do not object to the trials. In this context, it is relevant that the Report of the Working Group at the 101st MSC meeting provides that the Working Group

> *"agreed to take some parts of STCW [R]egulation I/13 as an additional reference to draw up these [Interim G]uidelines. In this regard, the [Working] Group also agreed, as instructed, to focus on objectives to be achieved when conducting MASS trials, thereby keeping the guidelines high-level. In this context, the Group noted that the "guidelines adopted by the Organization" referred to in [P]aragraph 3 of STCW [R]egulation I/13 would be these interim guidelines in the context of MASS trials as and when they were approved"*[34].

If so, the guidelines might even be the subject of indefinite trials, provided that a number of procedural requirements are met, including close involvement of the IMO and respect of any potential objections by other parties.[35]

In any case, it is clear that experimental trials foreseen in the Interim Guidelines will not provide a permanent solution for authorizing MASS in international waters. Proper endorsement of MASS requires a more solid legal backing, both in the form of formal convention amendments and through unified interpretations or guidelines, depending on the nature of the tension between MASS and the existing provision in question.

That said, the brief analysis above illustrates that the Interim Guidelines represent a potentially important first step towards introducing MASS in international waters, which in itself is significant. The absence of a geographical delimitation of the trial areas also raises the prospect that large sea areas surrounded by several coastal states that are favourable to MASS development could be the scene for individual trials on a more permanent basis. There is nothing in the text of the Interim Guidelines to exclude that prospect, as long as each individual trial meets the conditions for trials. A more generic trial area could be a prospect for sea areas, such as the Baltic Sea, that does not have transit traffic heading beyond its coastal states and which is fully covered by maritime zones belonging to the coastal states.

33 Ringbom, 2019, pp. 150–152.
34 IMO Doc. MSC 101/WP.8, para. 27.
35 STCW Regulation I/13(8).

To date, only one state has conducted a trial in accordance with the Interim Guidelines. In September 2019, the NYK Line, conducted the world's first MASS trial following the Interim Guidelines with the Iris Leader. The trial was conducted under two separate periods, both in sea areas which are "within the Japanese water".[36] According to a report submitted by Japan to IMO on the basis of paragraph 2.8 of the Guidelines, the Interim Guidelines "was very helpful […] to clarify issues to be addressed and consulted with parties concerned to ensure the safe conduct of trials". The report considered that they allow for flexible application for individual trials, and thus, that the guidelines "should be left as it is". Before the trial, following paragraph 2.8.1 of the Interim Guidelines, the relevant authorities were informed of the planned trial, hereunder the flag state administration, coastal state authorities, and relevant stakeholders, such as the classification society and insurance companies. Third parties were not informed beforehand, however, as it "was found that no information was necessary to be disseminated […] because these [trials] would be conducted under the condition of regular navigational watch."[37] During the trial, the "personnel involved […] were appropriately qualified and experienced", and officers where maintaining navigational watch, led by the supervision of the master of the ship. The navigation mode switched between the system of normal steering mode to autonomous operation mode under the supervision of the master of the ship (i.e. monitored autonomy).

In conclusion, it appears that the trial in question was not particularly challenging from a legal point of view because of the low degree of autonomy involved. The ship was not only monitored from a shore-based control centre, but also had a master on board, monitoring and approving the navigational operations.

More trials are likely to follow, also in international waters. In August 2020, the small (12 meter) Unmanned Surface Vessel Maxlimer had a successful three-week mission conducting deep-sea surveys on its voyage in the Atlantic.[38] The mission was supposed to cross the Atlantic to America, remotely controlled in a trans-ocean project, but was not possible to finalize "due to travel restrictions and other planning complications resulting from COVID-19".[39] The 15 meter trimaran Mayflower Autonomous Ship, which was supposed to commemorate the 400th anniversary of the famous voyage by the Mayflower in 1620 in September 2020, also had to postpone its start.[40]

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36 IMO Document MSC 102/INF.8, Annex.

37 Ibid., paras. 2 and 3.

38 'Robot Boat Completes Three-Week Atlantic Mission' BBC News <https://www.bbc.com/news/science-environment-53787546>

39 Seawork, 'SEA-KIT USV Successfully Completes 22 Days of Offshore Operation in the Atlantic Ocean' 2020) <https://www.seawork.com/exhibit/pr-and-marketing/press-releases/2020/sea-kit-usvsuccessfully-completes-22-days-of-offshore-operations-in-the-atlantic-ocean>.

40 https://newsroom.ibm.com/2020-03-05-Sea-Trials-Begin-for-Mayflower-Autonomous-Ships-AICaptain.

3.3.8 Bilateral or regional rules

In the absence of regulatory progress at IMO to permit the global deployment of MASS, pressure increases in and from states that wish to take a leading role in this development. It has been proposed that bilateral or regional rules might be put in place to permit the early mover to go ahead while awaiting the global regulatory regime to catch up later.[41] Indeed, regional solutions have sometimes been resorted to in the field of maritime safety and environmental protection, in order to accelerate regulation at the global level. A prime example in this respect is the maritime safety policy of the European Union, which has challenged the IMO's regulatory regime for decades by supplementing, complementing, and sometimes even competing rules for ships operating in the Union.

Usually, unilateralist challenges in shipping appear in a form where a state or region requires ships entering their ports (or, less commonly, their coastal waters) to comply with rules that go beyond the internationally accepted minimum requirements. The unilateral rules typically build upon, but are more stringent than the international rules, and ships may avoid the regional rules by choosing not to trade in areas where the rules apply.

In the context of MASS, the jurisdictional setting is different for two main reasons. First of all, it is mainly the flag state, rather than coastal and port states, that will be challenging the applicable international requirements when promoting MASS. The jurisdictional role of coastal and port states is confined to allowing or denying the use of MASS in their coastal waters. Until such a time when port states start proclaiming that they will deny non-MASS the right to enter their ports, any real decisions with respect to advancing the technology on board ships will rest with flag states.[42]

Second, and more importantly, it was already noted that by authorizing MASS, flag States will not only exceed international standards (by extending requirements to matters that are not currently regulated at the international level), but will inevitably also fail to be in compliance with certain key international safety and manning rules and raise important issues of interpretation with respect to many more such rules. This raises the

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41 See Marine Insight, available online: <https://www.marineinsight.com/shipping-news/mua-questions-amsas-motivations-autonomous-vessels>, where Australian Maritime Safety Authority chief executive Mick Kinley is reported to say that he "expected bilateral agreements between countries for the navigation of autonomous vessels within their waters before there was international regulation on the matter." See also the statement at the Norwegian Forum for Autonomous Ships, available online: <http://nfas.autonomous-ship.org/why-en.html>: "In reality, one may go a long way when autonomous ships are operated in national (as Yara Birkeland) or regional waters where one can manage with bilateral agreements between flag state, coast staes (sic) and port states, but general international shipping will be difficult to do without significant changes in today's regulations and contractual arrangements."

42 In theory it may be possible for coastal States to accept international trade by MASS between one or more states if the voyage can be made exclusively within the internal waters or territorial sea of the states concerned, and all coastal states are prepared to accept the arrangement. However, this possibility is not likely to be of any practical significance.

issue of compliance with UNCLOS Article 94 as well as issues of treaty law in relation to the flag state's treaty partners to the IMO conventions. Under the latter, treaties can be modified by some of the parties only under strict conditions that are not usually met for IMO conventions.[43] The flag state perspective also extends the geographical reach of the problem to being worldwide, rather than limited to ships trading in a given geographical area. Flag state responsibilities apply irrespective of the sea area concerned, and a violation of international standards may at least in theory be raised by any state "which has clear grounds to believe that proper jurisdiction and control with respect to a ship have not been exercised."[44] It may even be argued that flag state violations represent erga omnes obligations that a state has towards the international community as a whole and in whose protection all states have a legal interest, as opposed to violations vis-à-vis other states.[45]

Arguing that flag and port states unilaterally could agree between themselves to operate MASS in international trade, provided that all ports are covered, is jurisdictionally similar to arguing that the EU has the jurisdiction to allow EU-flagged MASS to operate between EU ports, or that a group of developing states could agree that they will not apply certain international safety rules in trade between them. The position underestimates the effect of flag states' violations of the existing IMO rules, which are inherent in this strategy, and that distinguishes this case from earlier unilateral initiatives to put regulatory pressure on IMO.[46] It is, moreover, quite a divisive strategy that is bound to foster and deepen disagreements between states on how MASS should be regulated at the global level in order to ensure the customary global consistency in shipping. In view of this, even a 'soft law' solution at the global level, such as a resolution or uniform interpretation, seems more valuable for facilitating MASS in a jurisdictional sense, than a regional treaty, EU regulation, or other type of unilateral 'hard' legal act.

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43 Under Article 41(1) of the VCLT, two or more of the parties to a treaty may conclude an agreement to modify the treaty as between themselves alone only if the possibility of such a modification is provided for by the treaty or if "the modification in question is not prohibited by the treaty," "does not affect the enjoyment by the other parties of their rights under the treaty or the performance of their obligations," and "does not relate to a provision, derogation from which is incompatible with the effective execution of the object and purpose of the treaty as a whole." See also rules to the same effect in UNCLOS, Article 311(2–4).

44 UNCLOS, Article 94(7).

45 Barcelona Traction, Light and Power Company, Limited (Belgium v. Spain), International Court of Justice, 1970. See also Article 48(1)(a) of the Articles on State Responsibility.

46 Even if the route of the MASS were to be confined to the territorial waters of the states involved, legal concerns could still arise, since in that case the MASS would be the ship exercising the rights of innocent and transit passage in other states' waters, invoking the duties to comply with international rules as required in UNCLOS Articles 21(4) and 39(2). This contrasts with the scenario discussed above, in which the MASS would operate permanently in the territorial sea of a coastal state and would therefore not be in international traffic.

3.3.9 Conclusions

The operation of autonomous ships in an international context is not yet lawful under current international law. Several legal issues stand in the way before flag states can be allowed to operate MASS. Most, if not all, of those issues could be resolved by appropriate action at the global level by the IMO. The review of various challenges linked to the authorization of MASS has highlighted the important role of the IMO, both in a technical and a jurisdictional sense.

With respect to the technical legal challenges, it is observed that rather few of the existing IMO rules pose direct conflicts with MASS. The prime example of conflict in the field of manning are the physical presence requirements for watchkeeping staff in STCW Chapter VIII, while the main challenges for increased automation lie in certain provisions in COLREGs, as these presume the presence of humans in the decision-making loop. Apart from this, several of the key maritime safety conventions include requirements that can only authorize MASS if understood and interpreted in a certain way, e.g. in terms of how to understand references to a navigation bridge in a remote operation context or how to deal with requirements that are redundant on ships without any persons on board etc.[47] This, too, requires action at the IMO level, albeit that the spectrum of available regulatory tools is larger in this case. Legal solutions that are 'softer' than formal regulatory amendments will normally suffice to achieve the desired result.

The crucial role that IMO plays in legalizing MASS is further highlighted in the international law of the sea. It is concluded that a key factor determining the legality of MASS is whether such ships are permitted under the 'generally accepted international rules and standards', which in reality is a shorthand for IMO rules. Through such references in several parts of UNCLOS, IMO is granted a central regulatory role, while UNCLOS maintains its function as a living, dynamic constitution that can be adapted to technological developments and the evolving needs of the international community, without compromising the international nature of regulation of shipping. More concretely, this dynamic nature has the effect that if IMO agrees to solutions for autonomous ships that are 'generally accepted' within the meaning of UNCLOS Article 94(5), those solutions override certain obstacles for MASS enumerated in paragraphs 3 and 4 of the sae article. By contrast, other regulatory entities, such as coastal states or regional organizations, have very little opportunities for independent regulation of this matter, at least outside the limits of their territorial sea. This applies both for coastal states seeking to advance the development of MASS and those seeking to limit the presence of foreign MASS in their coastal waters. In both cases, the relevant level of regulation that can be applied is highly dependent on existing IMO

47 For an overview of examples of such 'horizontal issues' in need of clarification, see the submission of the Comité Maritime International in IMO Doc. MSC 102/5/16.

standards. Even 'soft law' instruments adopted by the IMO carry more legal weight for authorizing MASS internationally than legally binding instruments of only regional scope.

The recently adopted Interim Guidelines for MASS trials may turn out to be the starting point for introducing MASS into international waters, and it has been shown above that their adoption may entail some legal consequences, despite their modest value as an independent source of international law. At the very least, the Interim Guidelines illustrate that the international maritime community is not unfavourable towards testing new technologies, provided that sufficient precautions are taken to maintain safety levels. As far as trials is concerned, it may well be that this tips the balance in favour of an assumed international acceptance, provided that the guidelines have been complied with.

Authorizing permanent MASS operations requires a more solid legal instrument to be developed by IMO. Apart from addressing the existing legal obstacles to the introduction of MASS, the main regulatory challenge for IMO will probably be to set out a legal framework for all the novel elements that MASS brings about. As noted above, the most urgent ones relate to setting standards for lookout by means of technology, remote operation of ships, and navigational decision making undertaken by autonomous systems.

This process has not yet started at IMO, which is still committed to analysing existing rules through the regulatory scoping exercise for some more years to come. In the meantime, other parties who have an interest in advancing MASS should probably start considering the format and content of the new rules. In any case, it seems inevitable that the completion of a first regulatory regime to authorize MASS will not be in place for many years. That is unfortunate, especially since even partially automated or periodically unmanned ships are in need of a resolution of many of the challenges before they can operate internationally.

The main risk posed by a widening gap between the expectations of progressive states and the legal reality is that the former start implementing their own solutions as flag states, and that MASS eventually becomes subject to different legal definitions and requirements in different parts of the world. The main driver for the introduction of MASS is the technological development that makes MASS possible and forms part of a broader trend of digitalization of society. Since this is not going to go away, ignoring the development is not an option for the world's leading regulator of international shipping. IMO deserves credit for having treated the matter very seriously from the outset. Further credit will be due if and when it shifts its attention from identifying problems in existing rules to resolving the entirely new legal challenges posed by MASS, which need to be addressed before the international deployment of MASS can take place.

3.4 National law

3.4.1 Finland

3.4.1.1 General

In a Finnish national context, three laws in particular are relevant for the developments towards MASS. These three laws are: the Finnish Maritime Code (Act 674/1994); the Act on the Technical Safety and Safe Operation of Ships (Act 1686/2009); and the Act on Ships' Crews and the Safety Management of Ships (1687/2009). The two latter acts, as well as the related government decrees and regulations by the Finnish Transport and Communications Agency (Traficom) adopted thereunder, broadly correspond to the content of the SOLAS and the STCW Conventions. COLREGs is implemented as such in the form of a 'blanket law' through regulation 538/77 and is also referred to in section 10 of the Water Traffic Act (782/2019). The most important tensions that MASS generate with respect to these laws are discussed below. Some of the identified issues are discussed in more detail in the case studies.

3.4.1.2 FMC (Master's responsibilities, shipowner's liability)

The part of the Finnish Maritime Code (FMC) that is most immediately affected by MASS developments is Chapter 6, which addresses the ship master's tasks and responsibilities. Even though it is not required explicitly, Chapter 6 implies that every ship needs to have a master. Among the obligations listed in chapter 6 that seem particularly relevant for present purposes is the obligation of the master to ensure the seaworthiness of the ship before each voyage, which includes an obligation to ensure that it is adequately manned, equipped and loaded in view of the prevailing circumstances (section 3(1)). The master shall supervise the condition of the ship throughout the sea voyage, and any seaworthiness problem that cannot be addressed underway shall be immediately notified to the owner/operator (section 3(1)-(2)).

The master shall also ensure that the ship is operated and handled in accordance with good seamanship (section 9(1)), which, as far as navigation is concerned, to a large extent amounts to complying with the COLREGs. The master is the representative of the ship owner/operator (section 13) but shall also safeguard the interests of the cargo owner (section 15) and may represent the cargo owner (section 16). Some additional duties in relation to the manning of the ship follow from other laws and regulations.[48]

The obligations of chapter 6 are accordingly laid down in the form of functions that need to be performed by the master. None of the provisions include an explicit obligation

48 In particular section 9(2) of 1687/2009 and section 5 of Government Decree 508/2018

for the master to perform those functions on board the ship, though several provisions clearly assume that this will be the case. For example, section 3 obliges the master to monitor the condition of the ship during the voyage, and section 6 – to ensure that all relevant documentation is on board. The provision that comes closest to an obligation for the master to actually be on board is section 6(3), which provides that the master may not leave the ship unless it is necessary because of the ship not being safely moored or anchored. Moreover, the master may not, under the same paragraph, be away from the ship in case of danger.

The master's obligations in distress situations and with respect to assistance at sea (chapter 6, sections 11, 11a and 12) raise similar concerns as those discussed above.

It is far from clear if a MASS can meet with these requirements. The first challenge is to assess whether a person who is not (even intended to be) on board the ship may actually be considered to be its master.

In view of the functional nature of the requirements, it may be argued that the question should also be answered in functional terms. In other words, if the functions of the master can be met in other ways than by his presence on board, one should not insist on his onboard presence. With the potential exception of section 6 (on the prohibition to leave the ship), the obligations of chapter 6 that relate to navigation and communication can probably be met without the physical presence of the master, provided that adequate monitoring and relay equipment is installed on board, and that the information transmitted from the ship is actively followed and monitored by a control centre. Whether appropriate safety and control requires physical presence by the master is another matter. While that is arguably the case on longer voyages, a ferry with frequent port calls and good opportunities for scheduled maintenance works could, for example, have those functions shifted to shore-based staff.

A second challenge relates to the level of automation involved. Even if it may be considered from a legal point of view that a master could operate 'remotely', the above scenario presumes that he/she – or somebody under his/her control – is more or less continuously attending the monitor and controls for navigational as well as safety purposes. If the operative functions (such as loading, navigation and manoeuvring) are highly automatized and the remote operators are only called to intervene if an alarm goes off, the ship is in reality navigated through pre-programmed software, which makes it even more difficult to argue that the obligations of chapter 6 are met. Surely the supplier or programmer of the relevant systems is unlikely to qualify as the master under chapter 6, as that person is no longer in the decision-making loop once his part of the work is completed. For highly automated operations, a 'designated person', e.g. linked to the ship operator, could always be nominated to assume the responsibilities of the shipmaster.

While that solution might satisfy the formal requirements of having a master, and hence resolve certain immediate legal hurdles, other obligations included in chapter 6 that focus on the tasks of the master (such as those relating to good seamanship or seaworthiness) would not be met by a person who is not part of the information and decision-making loop considering the ship's whereabouts.

It is, in other words, not feasible to impose duties that relate to tasks to be carried out on board the ship during a voyage, on a person, legal or natural, who is not on board. On the other hand, these duties are not so many. In fact, out of the duties enumerated in FMC Chapter 6, only a few relate to on-board activities. These include the duty to control that the ship's seaworthiness is maintained throughout the voyage (Ch 6, section 3(2)), the duty to ensure that good seamanship is maintained on the vessel (section 9(1)) and various duties that arise in extraordinary situations, notably distress (Ch 6, sections 11-12).[49] Apart from that, the duties listed can in most cases either be ensured in advance of the voyage or remotely by means of technological solutions, to be noted in the safe manning process, or they lose their relevance in an unmanned context.

It is also worth bearing in mind that the tasks and responsibilities listed for the master in Ch 6 of the FMC, are not responsibilities that exclusively lie on the master. As a matter of fact, most of them relate to the duty to operate the ship safely and are hence also - even primarily - the responsibility of the shipowner/reder.[50] The potential responsibility vacuum created by the absence of a master on board may therefore not be so big, and could be mitigated by making the responsibility for the safe operation of ships of the owner more explicit in Finnish legislation, for example in relation to the duties that apply under the ISM Code and apply under Chapter 3 of Act 1687/2009.

In summary, the challenges addressed here suggest that an amendment or addition to the part of the maritime code dealing with the master's responsibilities would be helpful before unmanned operations, especially with a high degree of automation, can take place in full compliance with the code.

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49 It is to be noted that the duty to provide assistance to persons in distress is not an absolute one. The FMC Ch 6, section 11, like SOLAS Regulation V/33 and UNCLOS Article 98 relate the duty to what can be feasibly done without endangering the own ship and its crew.

50 This state of affairs is particularly clear in the Norwegian legislation discussed in section 3.4.2 below. In Finnish law the duty of the carrier to ensure seaworthiness is explicit in relation to the cargo owner e.g. in chapter 13, section 26. See also chapter 6, section 3(3) which presumes an underlying responsibility of the reder for the seaworthiness of the ship.

3.4.1.3 Act 1686/2009 (technical safety standards)

For regular cargo ships in international voyages, there are few material differences between the international technical standards as referred to in SOLAS, and the national ones laid down in Act 1686/2009 on the Technical Safety and Safe Operation of Ships. The main difference relates to passenger ships in domestic traffic, for which the national law is coloured by EU law through the so-called 'Non-SOLAS Directive', extending many of the SOLAS provisions to the ships in question.[51]

Act 1686/2009 applies to commercial ships under the Finnish flag (section 3). Its overarching principle is laid down in section 5:

> *"A vessel used for navigation shall be such in design, construction, equipment and loading, or in such ballast and fitted with such necessary equipment, and also such in all other respects, that life, property and the environment may be considered to be safeguarded, having regard both to the nature of the fairways and the service on which the ship is engaged."*

However, the more detailed provisions of the act do not generally concern issues of particular relevance to MASS. It cross-refers to obligations under SOLAS, and mandatory codes thereunder, regarding ships' structure, equipment and operation, but also to rules outside the SOLAS Convention, such as load lines, tonnage measurement, surveys and certification. Apart from that, sections 6(3) and (4) further provide that SOLAS ships:

> *"shall also comply with the rules of a recognised classification society concerning the hull, machinery and electrical installations and automation of ships, or with equivalent regulations of the Finnish Transport and Communications Agency.*[52]
>
> *In order to ensure an adequate level of safety, the Finnish Transport and Communications Agency may issue more specific technical regulations on the technical and functional requirements under the SOLAS Convention, primarily through application of IMO Guidelines and Recommendations, and may approve safety structures, systems and equipment in accordance with the SOLAS Convention."*

Similarly, when it comes to exceptions for ships that "embody features of a novel kind", reference is also made directly to SOLAS (sections 7(2) and 8). The only independent national exemption being section 7(1), providing exceptional circumstances in which a ship that is not normally engaged on international voyages may be exempt from the requirement by Traficom under certain conditions.

51 Chapter 3 of the Act.

52 The reference to recognized organizations corresponds to SOLAS Reg. II-1/3(1).

However, section 10 offers considerably broader powers for the national authorities to provide for "alternative means of implementing ship safety arrangements", which may turn out to be relevant for approving MASS. Section 10 of the Act provides that Traficom

> *"may accept the implementation of safety arrangements on a particular ship by means alternative to those provided in the SOLAS Convention, if at least the same standard of safety is achieved by such means as in compliance with the provisions of the SOLAS Convention."*

Any exceptions or decisions on equivalents shall be notified to IMO (section 13). Notifications made by Finland under SOLAS to date do not have an immediate bearing on the development or approval of MASS.[53]

3.4.1.4 Act 1687/2009 (manning & watchkeeping)

The general national requirements concerning safe manning and competence of the crew are included in Act on Ships' Crews and the Safety Management of Ships (1687/2009) and in Government Decree on the Manning of Ships and Certification of Seafarers (166/2013), as amended. In addition, Traficom is given the authorisation to issue further provisions on the manning of ships in domestic trade under section 5(4) of Act 1687/2009.

3.4.1.4.1 Safe manning

The main national principle on safe manning is laid down in section 5(1-2) of Act 1687/2009:

"Every ship shall be manned in such a manner that the ship, crew, passengers, cargo, other property or the environment are not needlessly put at risk.

The ship's complement and the competence of the crew shall be such as to enable the proper performance of all onboard watchkeeping, safety- and security-related duties and duties related to marine pollution prevention."

The principles are broader than those referred to in SOLAS and UNCLOS, as they extend to a number of concerns beyond the mere safety and life of sea.

53 Only six notifications of equivalent solutions or alternative design are recorded on the IMODOCS website since the turn of the millennium. One deals with the requirement to carry a spare magnetic compass, one with launching appliances for rescue boats, two with nautical charts (accepting charts and nautical publications in digital format), and two concern lift machinery rooms on two identified passenger ships.

The proposal for safe manning of a ship is to be made by its operating company and approved by Traficom before the ship is put into service (section 6). The relevant considerations in assessing the matter are laid down in section 2 of the Government decree on the manning of ships and certification of seafarers (508/2018):[54]

> *"The company shall submit a proposal for the minimum safe manning level of every vessel, including an assessment of plans for the following:*
> *1) watch and security arrangements;*
> *2) hours of work and hours of rest;*
> *3) trading areas;*
> *4) frequency of port calls and length of voyages to be undertaken;*
> *5) mooring and unmooring of the vessel;*
> *6) cargo to be carried, cargo handling, stowage and securing;*
> *7) care for crew and passengers on board, including crew catering;*
> *8) operation, maintenance and repair of the vessel;*
> *9) operations for the protection of the marine environment;*
> *10) number, size and type of machinery;*
> *11) size, type and equipment of the vessel;*
> *12) onboard training"*

The principles to be considered by Traficom are referred to in section 7 of Act 1687/2009 and include the following:

> *"the principles of safe watchkeeping and the provisions on hours of work and rest in the Seafarers' Working Hours Act and the Act on Working Hours on Vessels Engaged on Domestic Voyages, the size and type of the vessel, the cargo carried on board, the engine output and automation of the machinery, the overall standard of shipboard equipment, service and maintenance, the trading area and the catch area, the number of passengers, catering and sanitary conditions and onboard training."*

Once satisfied, Traficom shall issue a safe manning document for the ship, indicating the minimum safe manning, the composition of the crew, and the required qualifications of the crew, with respect to different trading areas. The document shall be valid for a maximum of five years for ships in international trade, but may be indefinite for ships in domestic trade (section 6 of decree 508/2018). In the process, Traficom shall "request

54 Apart from these requirements, the form for application also include spaces for information on operational matters, such as handling of emergency situations, including fire, grounding, and man-over-board situations.

opinions on the application from the occupational safety and health authorities and the relevant national maritime labour market organisations." (section 6(3) of Act).

The possibility for owners and other parties to request an advance ruling on manning is specifically catered for in section 8 of Act 1687/2009, which obliges the authority to maintain its advance ruling in its final decision if circumstances have not changed.[55]

There are no specific requirements for minimum amount of crew members for ships in international trade, but section 6a of the Act, together with section 7 of Government Decree 508/2018, introduced a possibility for a simplified manning arrangement for ships, excluding tankers, of less than 500 gross tonnage engaged on domestic voyages in trading areas I and II:

> *"A passenger ship of 15 metres in length or less that carries more than 12 passengers on a voyage shall have a crew of at least one person. A passenger ship of less than 100 gross tonnage which carries 13 to 100 passengers shall have a crew consisting of at least the master and a deck hand. A passenger ship which carries 101 to 249 passengers shall have a crew consisting of at least the master and two deck hands.*
>
> *A cargo ship of 15 metres in length or less shall have a crew consisting of at least the master. A cargo ship of 15 metres in length or more and of less than 500 gross tonnage shall have a crew consisting of at least the master and a deck hand.*
>
> *When towing, the vessel shall have one deck hand in addition to what is laid down in subsections 2 and 3 above. If the vessel operates for 14 hours or more a day, it shall have at least two watchkeeping officers. If the engine room does not meet the requirements for an unmanned engine room, the engine room shall be attended when operating."*

The key question here is whether the onboard manning could be reduced to the extent that a safe manning document could be issued even if there is not a single crew member on board the ship. This, in turn, is closely linked to the question of whether tasks performed by the crew can be taken over by onshore controllers or, in the case of highly automated operations, by others responsible for the ship's operations.

Generally speaking, just like at international level, there appears to be no provision which would be directly violated if Traficom were to decide, as a matter of principle, that the functions required to ensure the safety of operations could be performed from other

55 Section 8(4). In Finnish "on noudatettava". The English translation is inadequate, only referring to a duty "to take proper account" of the advance ruling.

places than from the ship itself. 'Manned' is not the same as 'attended'.[56] Land-based controllers might very well be able to perform many of the operational functions remotely, while shore-based maintenance staff could easily undertake maintenance and service work, at least on near-coastal voyages. The guidelines on safe manning specifically provide that technical equipment and level of automation is to be taken into consideration when deciding on the manning levels.[57] Also, bearing in mind the purpose underlying safe manning as quoted above, it is not excluded that the operation of the ship might get safer if more functions are transferred to shore, as new types of situational awareness equipment, redundancy systems etc. are brought on board, and new functions will be performed from ashore.

On the other hand, the precise wording of the individual provisions should probably be considered with some care in this context, as it is evident that both the international and national rules on safe manning are drafted under the assumption that the crew is based on board the ship. The prospect of unmanned ships was not there at the time the rules were agreed on, and one should therefore avoid reading in too much into those legal texts. This is all the more true for fully autonomous operations, which stretch the notion of manning even further.

The most problematic provision for MASS with respect to manning is, ironically, the more flexible arrangements, requiring a minimum number of crew members, introduced for smaller ships in domestic traffic (section 6a). Strictly speaking, however, even those requirements do not explicitly require that those persons are on board the vessel. For AO-MASS these provisions will in any case represent a legal obstacle.

3.4.1.4.2 Watchkeeping

Generally, the Finnish national requirements on watchkeeping closely mirror those of the STCW regime. Under section 23(1) of Act 1687/2009 "the owner, the master, the chief engineer and the whole watchkeeping personnel shall ensure that watchkeeping arrangements are adequate for maintaining a safe watch or watches, taking into account the prevailing circumstances and conditions and the planned route of the vessel", a particular concern being the risk of fatigue. The more detailed requirements are laid down in TRAFI Regulation 16654/2011 on watchkeeping on ships, which contains detailed provisions for watchkeeping in various conditions, including requirements on lookout and radio watches.

56 The Oxford Dictionary defines the verb man as "work at, run, or operate (a place or piece of equipment)". www.oxforddictionaries.com/definition/english/man

57 See e.g. Guidelines on safe manning Annex 2, paras. 1.1.3 and 1.1.4.

TRAFI Regulation 16654/2011 also contains requirements for persons in charge of watchkeeping to be physically present on board.[58] While that regulation could be fairly easily amended at national level, it should be noted that the STCW Convention, on which the requirements are based, does not include specific exemptions or equivalence provisions for its watchkeeping part. It is thus not evident that an individual flag state can apply the presence requirements by analogy to shore-based remote-operation control rooms, without express support for such interpretation by IMO. A solution could be found in STCW Regulation I/13 on trials, discussed above in section 3.3.4. Under this Regulation, experiments to evaluate "alternative methods of performing specific duties or satisfying particular arrangements" (which may involve "the use of automated or integrated systems") can be authorised by the flag state administration for a limited period of time.[59] The maximum duration of such trials is not specified, but the procedure foreseen involves notification to IMO and a possibility for other IMO members to indicate their objections to the trials. Under Regulation I/13(8) administrations may authorize ships to operate with systems that have been found in the trials to be at least as safe as the regular requirements indefinitely, provided that certain conditions are met, including a close co-operation with, and some degree of endorsement by the IMO and its Maritime Safety Committee.

It seems difficult to meet the current national and international watchkeeping requirement on an unmanned ship, without some amendment and/or joint interpretation/ guidelines of the underlying STCW regime. On the other hand, it should be borne in mind that the reduction of onboard crew will normally be compensated by functions performed remotely. Just as in the case of manning, these land-based functions should at least to some extent alleviate the concerns related to fatigue etc.

3.4.1.4.3 Trials exception

The manning of MASS under Finnish law thus invokes important questions as to whether the required functions can be performed remotely, whether a remote operator could be the master of the ship, how to comply with the physical presence requirements, and whether the safe manning of an autonomous ship could be zero. However, where "necessary for trials of new technical solutions related to manning and watchkeeping", a 2018 amendment of Act 1687/2009, allows Traficom to permit temporary (maximum two years) trials for Finnish ships engaged on domestic voyages. Under certain conditions, the

58 See in particular TRAFI Regulation 16654/2011, section 4.3.5 requiring 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".

59 Under Regulation I/13(3), the flag state administration "shall be satisfied that such trials are conducted in a manner that provides at least the same degree of safety and pollution prevention as provided by these regulations."

requirements of sections 6, 6a, 7, 9, and 23 can be put aside in such trials and there would be no safe manning procedure regarding those trials. However, section 13a(2) continues:

> *"A precondition for issuing the permit is that the safety of the vessel or the environment will not be put at risk and that issuing the permit is not in breach of the international commitments related to shipping binding on Finland. The permit may include conditions."*

Provided that these conditions are met, there seem to be no immediate obstacles for applying these exceptions to trials with MASS in domestic traffic. It should be noted, though, that while the trials exception covers the relevant rules of Act 1687/2009, including section 9 on safe manning and the master's duties, it does not expressly provide exemptions from the master's duties under the Maritime Code. It would at least in part defeat the purpose of the exception if ships undergoing trials were obligated to have a master on board at all times. But in view of potential uncertainty on this matter, a clarification of Traficom's policy on the relationship between the exception and Chapter 6 of the Maritime Code would be helpful.

Apart from this, Finnish law has also introduced another recent exception, aimed at facilitating digitalization of maritime transport. Through Act 51/2019, the Pilots Act (940/2003) was amended to permit the possibility that pilotage is carried out remotely (sections 16a-16g). This option is subject to a permit by Traficom, which in turn may subject it to a series of conditions. Since the present report does not address remote pilotage, the matter will not be further discussed here.

3.4.1.5 Other

Finland has adopted one testing area for MASS. The so-called Jaakonmeri testing area is hosted by DIMECC Ltd and is available for any party seeking to perform tests regarding automated maritime traffic, (surface) ships or related technologies. It is for the applicant to seek and obtain all permits required for the testing, but DIMECC and authorities have the right to stop the trials. Based on the DIMECC testing rules, the applicant is subject to a series of obligations which require a standard of care significantly higher than for normal ship operation.[60] However, the legal relevance of those rules is uncertain.

60 For example, the test entity "is liable for any immediate, indirect damages or harm which results from testing. Test entity may be obligated to pay deposit, which is returned after the tests are completed" and "Testing entity needs to ensure that the vessels under tests do not cause danger to water traffic and that no external party can obtain the control of the vessel under test. Test entity also needs to ensure that the activities and operations in the test area do not cause disturbance or harm to people, environment, official traffic or the safe operations of the nearby nuclear plant." More information on the rules is available at https://www.oneseaecosystem.net/test-area/general-rules-test-area/.

3.4.2 Norway

The Norwegian legal situation is broadly similar to the Finnish one, which is natural as the two countries have an almost identical Maritime Code and are parties to the same IMO conventions covering a very wide spectrum of maritime safety rules. The two Norwegian laws that are most concerned are the Norwegian Maritime Code and the Maritime Safety and Security Act.

3.4.2.1 The Maritime Code

The Norwegian Maritime Code is essentially similar to the Finnish one, except for a different numbering system of the paragraph. Four Nordic States (Denmark, Finland, Norway and Sweden) jointly prepared the common bill for the act, and it remains a unique piece of law. Since 1994, a series of amendments have been introduced to the Norwegian Code, but those amendments are not relevant for present purposes. Nordic case law is therefore relevant when it comes to the Maritime Codes.

One of the relevant differences, which was there from the beginning, relates to Chapter 6 of the Code, addressing the role and responsibilities of the ship master. The Norwegian Code begins with the duty of the master to ensure the ship's seaworthiness, also during the voyage (section 131). This is followed by the duty to ensure that the navigation and management of the ship accords with good seamanship (section 132). In substance these duties closely correspond to sections 3 and 9 of Chapter 6 of the Finnish Maritime Code. Similarly, the master's duties in case of distress (section 135) correspond in broad terms with chapter 6 section 12 of the Finnish Act, and a similar provision preventing the master from leaving the ship unless safely moored and not in danger is included in section 136.

As it pertains to MASS, there is no main difference between Finnish and Norwegian law on the responsibilities of the master, or more generally, on the rules relevant to MASS. This similarity of rules does not exclude, however, that the provisions will be interpreted differently by courts and authorities in the two countries. Such variations have already developed in certain fields of relevance to MASS, e.g. in terms of the extent of a shipowner's liability for technical failures or in terms of how far a maritime operator may be subject to 'strict' liability in the absence of explicit laws to that effect,[61] but the extent to which such differences will apply to MASS remains to be seen.

61 Solvang, 2020, Collin 2020.

3.4.2.2 The Ship Safety and Security Act

Act of 16 February 2007 No. 9 relating to ship safety and security (hereafter 'the Ship Safety Act') is the principal act regulating maritime safety in Norway. It replaced the 1903 Seaworthiness Act and represents quite a different - and novel - approach to regulating the matter. It is a framework law which provides the main obligations in terms of objectives and general principles but leaves the detailed regulation to regulations (forskrifter) adopted by the 'Ministry', in this case the maritime authority (Sjøfartsdirektoratet). The Act therefore functions as the remedy for most of the national safety regulations in Norway. It covers technical and operative safety, but also environmental and security matters of relevance to ships. The main subject of the obligations in the Act, and the (hundreds of) underlying regulations, is the 'company' (rederi) within the meaning of the ISM Code, i.e. the person in charge of the operation of the ship (which broadly corresponds to the term 'reder' and Finnish term 'laivanisäntä'). At the heart of the regulation lies the company's duty to establish a safety management system and to keep it under constant review (chapter 2). The duties are usually in the form that the company shall 'see to', 'ensure' or 'cooperate' to achieve a certain outcome.[62] In certain cases, supplementary duties (usually in the form of cooperation duties) are placed on the ship master and other crew members, but they do not relieve the company from its duties. The Act also includes provision on enforcement and (penal and administrative) sanctions.

The following example, quoting section 6 on the company's general obligations, illustrates the dynamics between various type of obligations and actors under the Act:

> *"The company has an overall duty to see to that the construction and operation of the ship is in accordance with the rules laid down in or pursuant to this Act, including that the master and other persons working on board comply with the legislation.*
>
> *The company shall ensure that the statutory requirements are fulfilled, except for cases when the master by law is given an independent duty to ensure this. The company shall take steps to ensure that all the persons working on board have the opportunity to fulfil their obligations under the law.*
>
> *The Ministry may issue regulations containing further provisions relating to the obligations of the company pursuant to this provision."*

62 A difference between the duty to see to and the duty to ensure a certain outcome is that the former duty cannot be delegated and includes a duty of active follow-up and is hence stronger. On these terms, see the Government Bill for the Act NOU 2005:14, paras. 6.7.4.1 and 6.7.4.2 (pp. 109, 138) and Hernes Pettersen & Bull, pp. 138-144.

For the purpose of MASS, the duties of masters are more likely to be problematic than the duties of companies. In particular, section 8 provides that

> *"The master shall cooperate in the establishment, implementation and development of a Safety Management System in accordance with section 7, and shall participate in ensuring that the Safety Management System is complied with and is functioning appropriately.*
>
> *Others who are working on board shall, to the extent it is part of their positions, participate in ensuring that the Safety Management System is complied with on board.*
>
> *The Ministry may issue regulations on the duty to cooperate, including the right to deviate from the first and second paragraphs when this is required as a consequence of the implementation of the EEA Agreement."*

Section 19 lists more detailed duties of the master, divided into duties to ensure and a duty to cooperate. While the latter type of duties are not duties of result, the duties to ensure are, as they can be delegated but they cannot be done away with. While manning belongs to the less committing category in this respect, safe watchkeeping is to be ensured:

> *"The master shall ensure that:*
>
> *a) the ship is loaded and ballasted in a safe and proper manner and that the loading and unloading of the ship is carried out safely, cf. section 12, the Norwegian Maritime Code section 131 first paragraph and regulations issued pursuant to the provisions;*
>
> *b) the navigation of the ship and the keeping of ship's books are done pursuant to section 14, cf. the Norwegian Maritime Code sections 132 and 133 and regulations issued pursuant to the provisions;*
>
> *c) the watchkeeping arrangements on board do not compromise safety, cf. section 15 second paragraph and regulations issued pursuant to the provision; and*
>
> *d) necessary information about the ship, duties, basic environmental and safety provisions and measures to take in the event of marine casualties is given to other persons employed on board upon the commencement of work or assignment of work tasks.*
>
> *The master shall participate in ensuring that:*
>
> *a) the operation and maintenance of the ship is at all times carried out safely, cf. section 11 and regulations issued pursuant to the provision;*
>
> *b) the ship has the required certificates, cf. section 13 and regulations issued pursuant to the provision;*
>
> *c) the ship is safely manned, cf. section 15 first paragraph and the Norwegian Maritime Code section 131 first paragraph, and regulations issued pursuant to the provisions;*
>
> *d) the persons working on board, including himself, are duly qualified and have a valid medical certificate, cf. sections 16 and 17 and regulations issued pursuant to the provisions.*
>
> *The Ministry may issue further regulations on the requirements regarding the master in the first and second paragraphs."*

Some of the obligations are spelled out in a passive tense, including one of the key rules of relevance to manning and watchkeeping, section 15:

> *"A ship shall be safely manned.*
> *The watchkeeping arrangements on board shall be adequate to maintain safe navigation of the ship and other operating and safety procedures.*
> *The Ministry may issue further regulations on the requirements for manning and watchkeeping."*

It follows from section 6(1), quoted above, that this duty primarily lies on the company, and from 19(2)(c) that the master shall cooperate to this effect. More detailed rules, including exception opportunities, are laid down in the manning regulation (2009/666) and watchkeeping regulation, both of which are closely based on the IMO regime discussed above.

In summary, the legal situation in Norway with respect to MASS challenges is quite similar to the one in Finland. The key challenges are related to watchkeeping standards and the master's responsibilities, and– to a lesser degree to the rules on manning. In Norway there is no exception for trials comparable to the 2018 amendments to Act 1687/2009 in Finland (introducing section 13a).

3.4.2.3 MASS construction guidelines

In view of the many on-going concrete MASS projects in Norway, it has been necessary to adopt national procedures for how to bring these new types of ships and solutions into commercial operation in the absence of national and international rules for them. This is addressed in Guidelines (Veiledningsrundskriv) No 12-2020, as last updated on 24 August.[63] The guidelines rely on the existing IMO procedures for the approval of alternatives and equivalents, as provided for in IMO conventions (IMO Circular MSC.1/Circ. 1455). The IMO Circular, which is a 48-page long procedure for both (industry) submitters and administrations assessing requests for novel solutions to IMO requirements, based on an application from the party seeking to introduce the new solution to the national (flag state) administration. The Norwegian Guidelines only address MASS and do so in in a streamlined way, consisting of only 10 pages. The guidelines set out the procedures and material requirements for automation and remote operation for ships. They have a focus on building standards, but also include aspects such as certification, documentation, safety management system and testing requirements.

63 These guidelines are the only formal instrument adopted for this purpose in Norway. They are valid for five years, and are expected to be followed in practice by submitters and the administration alike, but their legal status is weaker than regulations adopted by the Ministry.

A starting point for the Guidelines is that MASS, whether autonomous or either wholly or partly remotely operated, shall maintain the same safety standards as conventional ships. They will therefore be assessed with respect to their degree of automation/remote control in addition to the body of laws that would apply to the kind of ship in question otherwise (passenger ship, cargo ship etc.) (section 1(2)).

The guidelines cover ships in Norwegian domestic trade. In view of their foundation in existing international procedures, they may serve as a useful blueprint for other states seeking to establish a national MASS approval framework.

3.4.2.4 Other

MASS test areas are administered by the coastal administration (Kystverket), who authorize such tests on a case-by-case basis. The legal foundation for this authorization is section 14 of the 2019 Port and Fairways Act, which requires that any activity that may impact navigability or safety, permanently or temporarily, requires a permit, either by the coastal authority or the municipality, depending on the case.[64] At least three different MASS testing areas have been approved by the coastal administration in Norway to date.[65]

Section 25 of the 2019 Port and Fairways Act opens for the concept of "autonomous coastal sailing".[66] Based on this provision, various kinds of MASS could be exempted from pilotage requirements, subject to a permit issued by the coastal authority.[67] The section, which is not limited to trials, also includes an interesting subsection, which requires the reder to "take all measures to prevent that the operation of MASS causes losses of human life or damage to the environment or property" (free translation). The required standard of care here is higher than that required for under the normal (civil or criminal) liability of shipowners for operating ships under the Ship Safety Act and the Maritime Code. On the other hand, the division of responsibility between the reder and the authority for such coastal pilot-free sailings is obscured by subsection 25(3), under which the reder's application for pilotage exemption" cannot be approved if the ship cannot navigate or manoeuvre safely in the area, or if there could be risks for loss of human lives, or damage to the environmental or property" (free translation).

64 See also https://www.kystverket.no/Nyheter/2016/oktober/startskuddet-gatt-for-samarbeid-om-autonome-skip/

65 Trondheimsfjorden (2016), Storfjorden (Ålesund) (2017) and Horten (2018)

66 https://lovdata.no/dokument/NL/lov/2019-06-21-70/KAPITTEL_1#§4

67 For the background, see e.g. https://www.regjeringen.no/contentassets/71e7f3060e2b45fa8636ed4ad007b200/los_h_n2018.pdf

3.5 The EU's role

Based on the Treaty of the Functioning of the European Union, it is clear that the EU in principle has competence to regulate matters relating to MASS, should it decide to do so as part of the common transport policy. So far, however, there are no EU rules specifically dealing with MASS, and the number of EU acts affected by the development is quite limited.

Out of the around 50 maritime safety-related directives and regulations adopted by the EU to date, only a few address technical requirements for ships or their operation, and even the ones that do, tend to address matters that are not of immediate relevance to MASS, such as e.g. oil tanker design (Regulation 530/2012) or the presence of certain equipment on board (Directives 2009/17 and 2014/90). The main exception to this is domestic passenger vessel safety, which is subject to an extensive body of EU requirements through Directive 2009/45 on safety standards for passenger ships, as amended, which essentially transfers the SOLAS requirements that normally apply to international voyages to a broad range of passenger ships operating in domestic voyages within EU Member States.

This means that the EU does not have an immediate role to play in legally enabling MASS. Since the main legal obstacles for operating MASS lie in the legal tensions they create in relation to existing international (IMO) conventions, EU does not have the tools to remove those obstacles. EU law can neither amend nor set aside public international law obligations, and cannot therefore address the legal obstacles on its own, even if the matter only concerned operations within the region.

In a jurisdictional sense, the Union has the same rights and obligations as a state, and it is a party to UNCLOS. Hence, it could impose additional criteria for EU-flagged MASS and establish common EU-wide criteria for MASS construction and operation. However, those measures would be regulatory tools to employ if the international rules were considered too lenient on MASS, which is not the situation today.

Once MASS are legally possible, the EU is likely to have an increasing role in keeping them safe and, if it so decides, to facilitate their development. Since legal feasibility is likely to commence in the field of trials, it is natural that the first project that the EU has undertaken focuses on drafting (non-binding) guidance for authorities and shipowners on MASS trials.[68] Once technology matures, the EU procedure for approving marine

68 An *Ad hoc* High Level Steering Group on Maritime Autonomous Surface Ships has been established and its main activity to date has been to develop operational guidelines for shipowners and authorities seeking to be involved with MASS trials. A draft of the guidelines is available at https://smashnederland.nl/wp-content/uploads/2020/01/201912-FINAL-draft-GUIDELINES-FOR-SAFE-MASS-EU.pdf

equipment (Directive 2014/90) is likely to be a key instrument, while the training aspect of MASS eventually will be subject to the EU Directive on training of seafarers (2008/106).

Outside regulation in the strict sense, the EU could also coordinate Member States' policies towards exemptions and equivalents, based on Article 6(1) of Regulation 789/2004 on the transfer of cargo and passenger ships between registers within the Community, and take an active role in driving the development of new international rules at IMO in the field of MASS.

In summary, until the international legal framework is in place to enable the operation of MASS, the role of the EU is likely to be limited to providing assistance and solutions for its implementation. Currently, those solutions exist in particular in the field of information and data systems, through various maritime data systems adopted under the frames of the VTMIS (2009/17) and Single Windows (2019/1239) directives.

The Union has at its disposal many practical tools for managing maritime information, as well as data that could prove relevant for the development of MASS. Notably, EMSA hosts and operates information and data tools handled by maritime authorities, with unlimited geographical coverage, that can support in the process of identifying suitable areas for MASS tests/trials, and during the performance of tests/trials. This support, whether of a more permanent nature or ad hoc, includes, in particular, the integrated maritime services, traffic density maps, and automated behaviour monitoring services. However, the EU's policy on if and how to make use of such tools has not yet been outlined.

Finally, it is worth mentioning that the European Maritime Safety Agency has initiated certain studies in this field, including one on the risk and regulatory issues related to MASS.[69]

3.6 MASS trials – Four scenarios

3.6.1 The scenarios

In order to concretize the issues linked to the approval of MASS trials, four scenarios will be addressed below through case studies. These are:

1) Internal waters (case study: free-going road ferry in Finnish archipelago)

69 SAFEMASS, 25.3.2020. Report No. 2020-0279 (DNVGL).

2) Domestic traffic/archipelago (case study: cargo ship in domestic regular trade, *e.g.* Hanko-Rauma)
3) Bilateral trade (case study: liner ship in regular traffic Helsinki-Tallinn)
4) Baltic Sea trade (case study: cargo ship in traffic Finland-Germany)

An effort to visually summarize the key legal challenges for the different trial scenarios is made in table at the end of this section.

3.6.2 Scenario 1: the road ferry option

In short-distance transport between two fixed points within internal waters, conditions for testing autonomous operations have many advantages. The range of navigational options in a fixed route is more limited and easier to overview. Communications links are normally strong and reliable in such areas, and assistance by shore-based personnel can be made available at short notice at any time.

Finland has almost complete regulatory authority over this type of transportation. First of all, the prescriptive and enforcement jurisdiction of Finland over road ferries is not limited under the law of the sea, as the sea areas in which these ships operate form part of internal waters.[70] Second, most IMO provisions, such as the main technical chapters, I-IV, of SOLAS, is limited to ships in international trade, and many of the remaining ones are usually limited to a size which excludes road ferries.[71] A third major distinction, with respect to applicable rules, is based on the more specific sea area in which the ferry operates. Most, if not all, road ferries in Finland operate in trading area I, i.e. in "areas in the inner archipelago, which are not directly exposed to swell from the open sea, as well as in short exposed fairway sections in the inner archipelago" (Act 1686/2009, Section 1(36)(a)).

At the same time, these waters are also part of Sea Area D, within the meaning of Section 1(38)(d) of the same Act.[72] This area division is based on the so-called 'non-SOLAS Directive', under which Sea Area D fall within the scope of the EU requirements for

70 Even if the ferry were not flagged in Finland, Finland would have jurisdiction in view of the proximity and interest in the trade in question.

71 SOLAS Regulation V/ 1(4) (500gt).

72 The definition reads in full: "Area D is the sea area whose geographic coordinates are at no point further than 3 miles from the coastline and where the probability of a significant wave height exceeding 1.5 metres is smaller than 10% over a one-year period."

passenger ships in domestic traffic, which are largely based on the SOLAS standards.[73] The domestic trading area I is thus a sub-category within Sea Area D. If a passenger ship is only certified to trade in domestic area I, it does not have to comply with the rules for Sea Area D of the Directive.[74] For those ferries, Finnish national standards apply, the more technical requirements being laid down in national regulations adopted by the competent authority (Traficom).

A further legal differentiation has to be made between free-going ferries and cable ferries. The latter is sometimes better viewed as a continuation of the road, having the consequence that cable ferries may not even be governed by the Maritime Code.[75] For present purposes, however, cable ferries are not further studied, as it is assumed that trial ferries will be free-going, along the lines of trials having already taken place in the country.[76]

As to the technical requirements, Finnish authorities have significant opportunities to issue exemptions and equivalent requirements on free-going ferries, provided safety is not compromised. This extends to construction and equipment standards as well as requirements on life-saving appliances or navigation equipment. If the ferry were certified to operate in Sea Area D, additional technical rules would follow from the 'non-SOLAS Directive'.[77] The EU regime also allows for exemptions and equivalences, but the procedure is heavier, as it requires EU involvement and endorsement from the Commission.

A similar flexibility does not extend to operational requirements, however. Road ferries are subject to a number of requirements that call for human involvement or intervention by the crew, such as the master's responsibilities, obligations for lookout, watchkeeping and communication and assistance to passengers in case of emergencies. Most of these

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73 In addition to the European sea areas, A, B, C and D, prescribed by the 'non-SOLAS Directive', Finland - and some other EU Member States – have introduced an additional category of sea (or 'trading') areas. Of relevance for road ferries is domestic trading area I, which is referred to in the section 2(36) of Act 1686/2009 on the Technical Safety and Safe Operation of Ships as "comprising rivers, canals, ports and lakes, and areas in the inner archipelago which are not directly exposed to swell from the open sea"; and further defined and mapped in in TRAFICOM regulation 7106/2010.

74 This is confirmed in para. 4.4 of TRAFI Regulation 523334/2019 on the safety on passenger ships on domestic voyages falling under scope of the 'non-SOLAS directive'. Para. 4.4 reads in Finnish: "D-luokan matkustaja-aluksiin, jotka liikennöivät yksinomaan kotimaanliikenteen liikennealueella I, saa soveltaa non-SOLAS-direktiivin liitteen I erityisvaatimusten sijasta voimassa olevissa teknisissä määräyksissä olevia kotimaanliikenteen liikennealueella I liikennöiviä matkustaja-aluksia koskevia vaatimuksia."

75 Their position under the Maritime Code is complex and not completely settled in domestic law. See also section 6 of the highways act 2005/503: "Ferries are subject to separate provisions pertaining thereto. Furthermore, the provisions of the Maritime Act (674/1994) and provisions pertaining to merchant vessels laid down under it apply to [free-going] ferry vessels where applicable."

76 See e.g. https://www.finferries.fi/en/news/press-releases/finferries-falco-worlds-first-fully-autonomous-ferry.html

77 Directive 2009/45/EC on safety rules and standards for passenger ships

(mostly national[78]) requirements are established in the form of functions to be performed, without explicit onboard requirements, but a few of them (most clearly in the field of watchkeeping) specifically call for the physical presence of the watchkeeping crew on the bridge or other relevant control station. On the other hand, since these rules are governed by national rules only, the recent provisions on exemptions for Finnish ships for the purpose of trial permits for maximum two years[79] would cover these situations.

With respect to safe manning, only national rules apply to domestic traffic. These rules are laid down in section 5 of Act 1687/2009, and in Government Decree 508/2018 on the manning of ships and certification of seafarers and may, for ships of this category involve the simplified manning rules set out in section 6a of the Act and section 7 of the Decree. In either case, the manning of MASS on a permanent basis would invoke important questions as to whether a remote operator on shore could be considered to be the master of the ship, or whether the safe manning of an autonomous ship could be zero. However, the 2018 amendment of Act 1687/2009 permits temporary trials in which these issues can be put aside, provided the authorities are convinced that "the safety of the vessel or the environment will not be put at risk and that issuing the permit is not in breach of the international commitments related to shipping binding on Finland."[80] Provided safety level is maintained, there seem to be no immediate obstacles for applying these exceptions to road ferries in domestic traffic.

As to the STCW Convention, it was noted above that the Convention does not strictly speaking apply to anyone who is not working on board ships. According to its Article III, the Convention applies "to seafarers serving on board seagoing ships" flying the flag of a state party (emphasis added). The term 'seagoing ship' is defined as "a ship other than those which navigate exclusively in inland waters or in waters within, or closely adjacent to, sheltered waters or areas where port regulations apply".[81] While it could be argued that ferries in sheltered waters could be exempted on this basis, the practice in Finland has been to apply the STCW, as implemented by domestic legislation, for free-going ferries.

The COLREGS extend to internal trade and internal waters and apply to free-going ferries without particular exceptions. This, as noted above, involves some question marks with respect to the higher level of automation.

78 But note that SOLAS Chapter V does apply to domestic voyages, depends on size limits etc.

79 2018 amendments to § 13 of Act 1687/09 (2018/976).

80 Section 13a.

81 STCW, Article II(g). More generally on the term 'seagoing ship', see e.g. the study by Prof. V. Lowe in IOPC Funds doc. IOPC/OCT11/4/4, Annex 1.

The main regulatory challenge for this category of ships relates to the presence of passengers on board, which triggers a whole series of technical and operational standards in addition to those that apply to other forms of commercial ships.[82] Passengers need to be informed, guided, evacuated, and rescued, and these are not easy tasks to perform remotely, no matter how well aware the shore-based staff may be of the situation. This is a field which requires particular attention by both ship operators and authorities. Until satisfactory solutions are found, a single crew member on a ferry, who is not necessarily in charge of navigation but may have a series of other tasks, may be an interim solution.

3.6.3 Scenario 2: the domestic trade option

The scenario where a cargo ship is in domestic trade between two more distant Finnish ports, but still trafficking within Finnish territorial waters, is more technically demanding in many ways. Navigation as such is more challenging in the archipelago, the range of variables to take into account grow with the extended route, and there is less instant access to repair and maintenance work.

However, from a regulatory point of view, this scenario is similar to the first one. In fact, it involves less regulatory hurdles, given that the transport does not involve passengers, which means that a range of rules, including EU rules, do not apply.

As far as the law of the sea is concerned, the ship mainly operates in internal waters in which the jurisdiction of the coastal state is complete. Even if the route would involve segments in the territorial sea, national jurisdiction would still apply, and other states' rights would not be involved, as long as the right of innocent passage of other states' ships would not be affected, and as long as other ships would be duly informed.

As to the technical rules, the situation is also largely the same as for the ferry-scenario. The main technical parts of SOLAS do not extend to ships in domestic trade. For these cases, national provisions, which provide larger opportunities for national exceptions and variations, provide the basic technical standards. However, since a ship in this trade may very well be larger than a 500gt, a number of SOLAS Chapter V provisions would apply directly. This concerns a series of requirements concerning bridge design, equipment, and

82 Section 7(3) of Act 1687/2009 requires that "the ship shall be sufficiently manned to ensure the proper use of life-saving, fire-fighting and other safety equipment, the performance of the duties specified in the muster list, the security duties and the duties related to marine pollution prevention." Passenger safety is also included among the chief purposes of safe manning as referred to in section 5(1) of Act 1687/2009 quoted above.

systems,[83] but does not extend to safe manning requirement, which is limited to ships on international voyages. In line with this, if the ship is less than 500gt and only operates in trading areas I and II, it could under Finnish law be manned through a simplified procedure based on section 6a of Act 1687/2009 and Decree 508/2018. As was the case for the ferry-scenario, it seems that permanent MASS operations would raise important questions of principle, while trials of less than two years could benefit from the exemption in section 13a of the same Act.

It may be questioned, however, whether the national exception can be applied in this case. The rule in section 13a only applies to permits issued "for a restricted area and for trials carried out on a Finnish vessel engaged on domestic voyages". In the absence of a definition of 'a restricted area' it may be argued that ships in regular domestic voyages qualify, even if part of the journey is undertaken beyond the baseline.[84] However, the section also requires that the permit is not in violation with international commitments.

In this scenario, it is possible to argue that the STCW, including its watchkeeping requirements, applies directly if there are seafarers on board the ship. It was noted earlier that the convention applies to 'seagoing ships', which is defined as "a ship other than those which navigate exclusively in inland waters or in waters within, or closely adjacent to, sheltered waters or areas where port regulations apply".[85] If the route involves large stretches of unsheltered waters, the STCW rules could thus limit this type of operations, even if trade is purely domestic. In that case, a key question would be if an exception could be justified under Regulation I/13 of the STCW referred to above, which would involve closer liaison with the IMO.

3.6.4 Scenario 3: the bilateral trade option

3.6.4.1 Introduction

The shift from domestic to international trade signifies a major shift in applicable rules, even if the length of the voyage may well be shorter in this scenario. The rules that govern this type of trials are mainly international. International voyages trigger the applicability of a broad range of international rules, and the availability of special solutions by the flag

83 Regulations V/15-V/28, as referred to in Reg. V/1(4). These requirements are somewhat loosened by the possibility to offer exemptions and equivalents for individual ships in Regulation V/3(2) and by the general option not to apply Chapter V to ships exclusively trading in internal waters (Regulation V/1(2)). See also the corresponding section 11 on national exemptions in Act 1686/2009.

84 See also Government Bill HE 43/2018, p. 15: "Rajoitettu alue voi olla myös esimerkiksi tietty reitti. Kokeilulupaa harkittaessa otettaisiin myös huomioon aluksen mahdollisesti aiheuttama vaara muulle liikenteelle tai ympäristölle."

85 STCW, Article II(g). More generally on the term 'seagoing ship', see e.g. the study by Prof. V. Lowe in IOPC Funds doc. IOPC/OCT11/4/4, Annex 1.

state are more limited. Similarly, the national rules that permit exemptions from manning and watchkeeping standards for trial purposes only apply to domestic voyages.

3.6.4.2 Law of the sea

International voyages, by definition, involve at least two states' coastal waters. In the Helsinki-Tallinn scenario, those coastal waters are the internal waters, territorial sea and the EEZ of both states, but there is no stretch of the high seas on the route.

Practicalities, but also law of the sea considerations, require that both states involved in the voyage agree on the operation of MASS. It is therefore assumed that neither state will object to the operation of the MASS in question in their own coastal waters.

However, since the voyage involves traffic outside their territorial waters, the question is whether other states may object to the presence of such ships. It was noted above that UNCLOS Article 56(2) requires that coastal states exercising their rights and performing their duties in the EEZ "shall have due regard to the rights and duties of other States and shall act in accordance with the provisions of the Convention." While it is clear that all ships enjoy freedom of navigation in the EEZ, and that the safety of navigation represents an interest of all states for which due regard shall be had, UNCLOS does not offer much further guidance on how to deal with this type of conflicts of interest. Article 59 lays down the general formula for resolution of jurisdictional conflicts in the EEZ: "the conflict should be resolved on the basis of equity and in the light of all the relevant circumstances, taking into account the respective importance of the interests involved to the parties as well as to the international community as a whole."

It is obvious that the safety of navigation represents a very strong interest "to the international community as a whole", but the guidance offered by the clause is so elusive that it is argued that a better way of approaching the matter is through the IMO Conventions themselves. This is also supported by the general mechanism of UNCLOS for dealing with technical rule-making for shipping by means of referencing to 'generally accepted' or 'applicable' international rules and standards that flag states are to implement for their ships regardless of the sea areas concerned.[86]

3.6.4.3 IMO Rules

For international voyages the IMO rules generally apply in full. As far as SOLAS is concerned, flag states would still have possibilities to issue exceptions and equivalents for

86 UNCLOS Articles 94(5), 211(2)

many technical requirements of its ships under Regulations I/4 and I/5. But with respect to the requirements of Chapter V on safety of navigation, the available exceptions would no longer be available, except for ships below 150gt under Regulation V/1(4)(1). The rules on safe manning apply, but it was noted that they are functional in nature and offer a broad degree of discretion for flag states, inter alia, to accommodate technical solutions to perform the functions.

On the basis of the review above, the most challenging IMO obligations for MASS to meet were considered to be the watchkeeping requirements of the STCW Convention, calling for the physical presence of certain key crew members at all times. However, since the present scenario relates specifically to trials, reference should be made to Regulation I/13 of the STCW Convention which specifically provides for rules for the conduct of trials,[87] potentially even on a longer-term basis.[88]

Regulation I/13 is complex and includes a number of conditions for trials, but it could well be the basis for this type of trials, provided the (flag state) authority is satisfied that at least the same degree of safety and pollution prevention as under the regular rules is maintained.[89]

One of the main limitations of the Regulation with respect to MASS is the possibility it offers for other states to object to the trials, possibly by barring ships participating in the trials from doing so "while navigating in [their] waters".[90] In the present scenario, however, this is not relevant as no other coastal states will be involved in the trade.

Another condition is that such trials "shall be conducted in accordance with Guidelines adopted by the Organization".[91] While the negotiating history of that provision points to earlier experiments with a single person on watch in the hours of darkness,[92] the MASS Working Group, when preparing the Interim Guidelines, took the view that the guidelines referred to in STCW Regulation I/13 "would be these interim guidelines in the context of

87 In paragraph 2 of Regulation I/13, the term 'trial' is defined as "an experiment or a series of experiments, conducted over a limited period, which may involve the use of automated or integrated systems in order to evaluate alternative methods of performing specific duties or satisfying particular arrangements prescribed by the Convention, which would provide at least the same degree of safety and pollution prevention as provided by these regulations."

88 Despite the wording of para 2 (quoted in previous footnote), para. 8 admits the possibility of indefinite application, subject to a number of strict conditions, including approval by the IMO's Maritime Safety Committee.

89 Paras. 3 and 8(2).

90 Paras. 6 and 7 of Regulation 1/13.

91 Para. 3.

92 A couple of MSC circulars from the 1990's are specifically referred to, but these trials have not been widespread in practice due to opposition of certain states. See Ringbom, 2018, at pp. 150–152.

MASS trials as and when they were adopted".[93] If this approach is accepted, the Interim Guidelines might authorise exceptions in this field, which could have wide-reaching implications, in particular where none of the coastal states involved in the ship's journey would object to the trials.

Relaxations of the watchkeeping requirements could thus be legitimized as an "experiment ... [involving] the use of automated or integrated systems in order to evaluate alternative methods of performing specific duties",[94] provided that a number of procedural requirements are met, including close involvement of the IMO.[95]

More broadly, as was noted above, the Interim Guidelines for MASS Trials could be used to justify trials with respect to any IMO convention, as long as the intent of those conventions are met. This applies without limitation to geographical areas and could be relevant in fields for which the legal situation is not entirely clear, such as the use of remote crew members to perform the onboard duties. Compliance with the interim guidelines would also provide a basis for arguing that the trials, despite certain variations with the main rules, form part of the 'generally accepted' international rules accepted by the IMO.

Finally, it should also be noted that the conditions surrounding this particular scenario offer a rather convenient way of ensuring compliance with the most challenging IMO rules. Since the most demanding elements of the trial relate to the period in which the ship navigates in the EEZ, it is possible to avoid potential criticism against the trial by having persons on the bridge, with a duty to monitor navigation and intervene where necessary, for the periods that the ship navigates in international waters. In the Helsinki-Tallinn scenario, this part only represents a stretch of a few nautical miles per voyage.

3.6.5 Scenario 4: the Baltic Sea option

This scenario is fairly similar to scenario 3 in terms of setting and applicable UNCLOS provisions and IMO rules. In this case, the route of the vessel involves traversing coastal states' waters, i.e. maritime zones (in particular the EEZ) of states where the ship does not make port calls. This difference has a number of practical limitations as it will reduce the benefit of having the bridge manned in international waters (as was suggested in scenario 3 above), and increased distance from shore will also place additional strains on ship-to-shore communication capacity. From a legal point of view, the coastal states along the

93 IMO Doc. MSC 101/WP.8, para. 27.

94 Para 2.

95 STCW Regulation I/13, paras 4-8.

route may not have a general power to prevent the passage of MASS through their EEZ,[96] but individual conventions, such as notably STCW Regulation I/13 may nevertheless offer them an opportunity to do so. This highlights the importance of securing some form of acceptance by all states along the ship's route.

Provided that all coastal states of the Baltic Sea would be favourable towards MASS trials, the law of the sea offers an interesting opportunity to go further, by jointly establishing the Baltic Sea as a whole, or parts of it, as a testing area for autonomous ships. This opportunity is jurisdictionally founded in the absence of through traffic in the Baltic Sea, i.e. in the fact that virtually all ships in the area are bound for some port in the region. The nine states acting in concert could thus collectively exercise their jurisdiction as port states, by seeking foreign ships' readiness to accept the presence of MASS in the area as a condition for granting access to their ports. That line of action would have its legal foundation in the absence of a right of ships to enter foreign ports, and the consequential right for port states to place conditions for foreign ships' access. It would be assisted by the fact that the Baltic Sea is already 'covered' by coastal zones of the littoral states and that there are no more stretches of high seas in the region. Each point of the sea hence belongs to the quasi-territorial interest zone of one of the littoral (port) states, which reduces the extraterritorial effect of the claim. Such presumed consent could not, however, extend to ships that only navigate in the Baltic Sea without making a call at any of the ports.

There are no strict rules available for determining the legality of such an approach. In the end, the legality of the approach would depend on a series of more general considerations of 'reasonableness' under international law, such as proportionality between the effects of the measure and the objectives, and the absence of discrimination or abuse of right. The impact of such a MASS area on other ships is expected to be very limited which works in favour of considering such an approach lawful, provided all states participate.

For a variety of reasons, however, including the overall assessment of reasonableness and the policy tradition of the Baltic Sea states in shipping matters, it would be preferable to have this arrangement endorsed by IMO, rather than set up unilaterally by the nine states. The formal nature of the endorsement is of lesser relevance in this context, and here, too, the current IMO Interim Guidelines for MASS Trials may very well provide the backdrop for such approval.

96 See Ringbom 2020, who also notes that coastal states' possibilities to intervene with the passage foreign MASS through their territorial sea is also limited, but offers more opportunities than in the EEZ.

3.6.6 Conclusions on the scenarios

The main legal challenges may be summarized in the following table:

Table 4. Summary of legal challenges for various MASS trial scenarios

Legal challenge		1 Ferry				2 Domestic				3 Bilateral				4 Baltic Sea			
		R/M	R/U	A/M	A/U	R/M	R/U	A/M	A/U	R/M	R/U	A/M	A/U	R/M	R/U	A/M	A/U
UNCLOS											94		94		94		94
	STCW watchkeeping					VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13	VIII/2 I/13
	COLREGS lookout	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	COLREGS nav.decisions			2, 6, 8	2, 6, 8			2, 6, 8	2, 6, 8			2, 6, 8	2, 6, 8			2, 6, 8	2, 6, 8
	SOLAS Ch I-IV (alt., except)									I/4, I/5 II-1/55, II-2/17, III/38, IV/3							
	SOLAS Ch V	1(2) 1(4)	1(2) 1(4)	1(2) 1(4)	1(2) 1(4)	1(4) 3(2)	1(4) 3(2)	1(4) 3(2)	1(4) 3(2)		33 & more		33 & more		33 & more		33 & more
IMO Conventions	SOLAS Ch V/14									V/14 + GL	V/14 + GL	V/14 + GL	V/14 + GL	V/14 + GL	V/14 + GL	V/14 + GL	V/14 + GL
EU rules	Non-Solas Dir.	Equiv (EU)	Equiv (EU)	Equiv (EU)	Equiv (EU)												
	FMC 674/1994		Ch 6		Ch 6		Ch 6		Ch 6		Ch 6		Ch 6		Ch 6		Ch 6
	1686/09 (exemptions)	23(2)	23(2)	23(2)	23(2)	7-11	7-11	7-11	7-11	7-11	7-11	7-11	7-11	7-11	7-11	7-11	7-11
Finnish law	1687/09 Manning Watchkeeping Exception	5, 6a 23 13a	5, 6a 23 13a	5, 6a 23 13a	5, 6a 23 13a	5, 6a 23 13a	5, 6a 23 13a	5, 6a 23 13a	5, 6a 23 13a								

R/M= Remote, partly manned; R/U= Remote unmanned; A/M= Autonomous, partly manned; A/U Autonomous unmanned
Grey - potential challenge (could be resolved by interpretation/guidelines)
Black - certain challenge, probably requires change of regulation.Table 4. Summary of legal challenges for various MASS trial scenarios.

In terms of legal challenges, the four scenarios above can be divided in two main groups: domestic trials (1 and 2) and international trials (3 and 4). All four types of trials are possible within the existing legal framework, but both groups require favourable opinions and permissive interpretation by key stakeholders. For the domestic trials, endorsement by the flag (and coastal) state administration in Finland represents the key, while the international trials additional presuppose that the governments of the participating flag and port states support the activity, and that the coastal states along the ship's route at least do not object to it. In some cases, IMO should be notified of the international trials, but the organization or its members do not have a role in formally approving them.

This legal situation is arrived at through the recent introduction of a few key instruments aimed at enabling MASS. In particular, the 2018 amendments to Act 1687/2009 (introducing section 13a) serve to address the most important legal obstructions at domestic level linked to manning and watchkeeping, and arguably also the implicit requirement for a master to be on board the ship under the Maritime Code. At international level, the Interim Guidelines, if generously interpreted in respect of the 'intent' underlying existing rules, could provide a basis for international trials that fail to meet the applicable international standards.

Arguably, therefore, the existing legal framework no longer prevents dedicated MASS trials in the Baltic Sea. Authorities by now have the needed tools to authorize the basic trials. It is not necessarily straightforward or clear to apply these tools in practice. But, in the absence of obvious legal 'showstoppers', they offer a basis for authorities seeking to approve MASS trials, both domestically and in international trade. Consequently, companies seeking to carry out trials can focus their attention on convincing the authorities that safety requirements are being met, rather than demanding regulatory intervention.

That proposition, however, presumes a fairly far-reaching interpretation of the effect of the IMO Interim Guidelines, which may not be universally endorsed. An interim solution to cater for legal concerns by others would be to keep part of the crew, including a master, on board the MASS during the trial. If that person could physically monitor the navigation of the ship and, where necessary, take control of the operation, many of the most pertinent legal doubts linked to MASS operation (including the COLREGS requirements calling for human presence in the decision-making loop, the watchkeeping requirements of the STCW, and the presence of a master on board) could be addressed. Based on the analysis above, this solution would seem particularly valuable to implement for the parts of the voyage in which the MASS operates outside the territorial waters of its flag and port states, and where it is likely to interact with other traffic. This suggests that the method is more suitable for trials with a shorter international transport leg, i.e. is better suited for case study 3 than four case study 4.

The main limitation linked to MASS trials is that trials by definition only represent a temporary relief to the identified legal concerns. In the case of domestic law this period is limited to two years, while the IMO Interim Guidelines provide some more flexibility.

The use of pre-determined national trial areas for the purpose, such as *Jaakonmeri*, do not provide immediate legal advantages compared to other (domestic) trials, but such areas may nevertheless provide favourable conditions for infrastructure, publicity, and alerting other traffic, and therefore be more likely to be positively considered by authorities.

In any case, it is important that trials are well-publicized and closely follow the applicable formal requirements, of which there are few to date. For international trials, a close involvement by the IMO is essential, not only for meeting the standards of the Interim Guidelines, but an open communication also helps to achieve international backing for the trial as well as alerting other states and shipping actors about the activities. All this forms part of the due care that a prudent maritime administration may be expected to exercise when approving real-life tests of novel technologies.

3.7 General conclusions on the legal challenges posed by the existing regulatory regime

The existing legal challenges linked to operating MASS depend on four main issues:

- The sea area concerned
- Applicable substantive law
- The level of autonomy of the operation
- Whether or not the operation is a trial

These elements will be summarized separately below, followed by a brief review of how a future international regulatory regime for MASS might be designed.

3.7.1 Sea areas

The physical location of the MASS operation is critical, as it determines the level of state jurisdiction over the operation and - through that - what substantive laws apply. However, the single most important factor in deciding on applicable rules and their interpretation is the flag state in question. Flag states' jurisdiction and regulatory authority over its ships applies regardless of sea area involved.

Generally speaking, operations in territorial waters (internal waters and the territorial sea) of a state are governed by rules of that state only, assuming that it is also the flag state of the MASS. If the operation extends beyond these zones (to international waters), the interests of other states and ships navigating in the area will increase. Trade between two or more states require at least implicit support of the port states involved. In a regional sea without significant passing traffic, like the Baltic Sea, port state jurisdiction may also be utilized for placing particular requirements on ships in the area, provided all littoral states collectively agree to such measures. Such conditions could relate to certain equipment or operational standards, or merely involve a requirement to accept the presence of MASS in the area.

In the technical IMO rules, the range of obligations also increases for international navigation, but the criteria normally focus on whether the ship is in domestic or international trade (SOLAS Reg. I/1 and I/3) and may in some cases depend on the proximity of the trade to the nearest coastline (e.g. SOLAS Reg. V/3(2)), rather than on the maritime zones involved. Some IMO rules, however, apply in all sea areas (COLREGS) and, in some cases, the applicability to domestic voyages can depend from one case to another (STCW Reg. II(g)).

Nothing prevents the EU from establishing guidelines for MASS operations taking place in coastal waters of EU Member States, but the EU cannot resolve legal tensions in relation to IMO conventions.

3.7.2 Substantive maritime safety law

The starting point is that MASS requirements will exist alongside requirements that would otherwise apply to the ships in question. Different requirements will therefore apply to MASS depending on the category of ship and cargo involved, as well as on whether or not they carry passengers. The relevant material standards are mainly to be found at either global (IMO) level or in the national rules of the flag states.

EU maritime safety rules have a lesser role in this regard, but their applicability may concern MASS with respect to certain ship types (passenger ships in domestic trade) or specific issues that are subject to EU regulation (such as crew training or transfer of MASS between EU registers).

Generally, neither national nor international maritime standards involve direct regulatory conflicts with respect to MASS. The main example of such a general conflict is the requirement in STCW Chapter VIII concerning physical presence on the bridge and other places on board.

Current obligations relating to lookout, unexpected events (such as distress situations), assistance and specific duties of ship masters and other onboard crew members (such as the ship's security officer) may also be legally problematic under existing rules. Those duties, moreover, do not normally include express possibilities for exemptions and equivalent arrangements. Apart from that, as is discussed below, increased autonomy levels generate additional regulatory complications.

However, apart from requirements relating to physical human presence, the international rules do not strictly prohibit the development towards autonomous shipping, provided that it can be done without endangering safety and that all functions required in the rules can be performed in alternative ways. The rules are laid down in the form of functions to be performed, without specification as to how that is to be achieved. This is also the case in respect of manning of ships, which obviously is a key issue for the legal status of MASS.

The relative absence of direct legal conflict is significant because it allows a broader range of tools for addressing the problem. In particular, it opens up for IMO to move the matter forward by making use of measures that are less heavy than convention amendments, such as joint interpretations, clarifying resolutions etc. For example, many of the legal concerns and questions relating to the position of the master and the crew could be resolved by formally agreeing jointly among IMO members that those functions may be performed remotely.

The regulatory situation is similar in national law, which strongly builds upon the international rules. Some additional flexibility is offered in Finnish law with respect to ships engaged in domestic trade, for which the international rules either do not apply or offer opportunities for national arrangements. Nothing excludes that national arrangements based on flexibility in the conventions is applied to Finnish ships in international trade.

3.7.3 Level of autonomy

Different aspects of MASS give rise to different legal issues. For example, remote operation does not raise questions of principle relating to the exercise of 'good seamanship', as that seamanship may well be exercised from a different location than the ship itself. By contrast, it raises a series of issues linked to the relationship between the MASS and its control centre, including communication standards and emergency procedures. Conversely, MASS that operate autonomously without human involvement raise issues with respect to any rules that presume that there is a human in the decision-making loop, including COLREGS and various maritime liability rules.

A way of avoiding both types of legal objections would be to only unman and automate the MASS to a certain degree. As long as some persons are retained on board, preferably one with master's qualifications, many of legal concerns could be alleviated, at least in an interim period, to allow for technologies to mature and to increase public receptiveness towards MASS.

3.7.4 Trial or not

It follows from the above that characterising MASS operation as a trial may make a significant legal difference as to the applicable requirements. This is due to two recent developments in particular: the adoption of the Interim Guidelines at IMO and the inclusion of the trial's exception into Finnish Act 1687/2009. The latter instrument is relevant for domestic operations of Finnish ships only, while the IMO Guidelines cover a broader range of potential trials. On the other hand, while the Finnish exception is solidly anchored in domestic legislation, the IMO Guidelines is a non-binding instrument which cannot, as such, override legal obligations. However, it is considered that the guidelines may nevertheless have an important legal role in highlighting the international dimension of, and support for, the MASS development, which may turn out to be crucial if states were to protest against MASS trials in international waters.

Practical considerations relating to infrastructure, traffic and general public support, may well speak in favour of executing the trial in a pre-established dedicated trial area, but this would not in itself remove or alter any of the legal rights or obligations linked to MASS trials.

3.7.5 Changing the international regulatory landscape

Trials provide a useful way to permit MASS operations in a real-life environment in the early phases of their development. In the longer run, however, it is clear that MASS cannot rely on rules concerning trials, and even less so on 'soft law' solutions, to address the differences between MASS and traditionally operated ships.

The most important institution for creating a solid legal basis for MASS operation is the IMO. If the rules of IMO are adequate, other levels will follow, including the jurisdictional rules of the law of the sea and national laws. Conversely, it will always be difficult to justify international MASS operations in the absence of specific rules to that effect at IMO.

Based on the above, some key amendments seem necessary before a solid legal basis can be said to exist for MASS, at least in its more developed forms. The watchkeeping provisions of the STCW have been particularly highlighted, and parts of the COLREGs and SOLAS would also benefit from legal intervention to clarify some outstanding key issues on the legality of technological situational awareness tools and the legality of remote and automated decision-making. Apart from that, a range of clarifications are required with respect to the existing uncertainties (e.g. relating to the role of the master, safe manning, and on how to deal with access and life-saving requirements, documentary requirements, control procedures etc. on ships with no crew on board). However, they do not necessarily need to take the form of formal amendments, as they could be addressed by less heavy interpretative tools.

The clearest legal solution for MASS would be to establish a regulatory framework of its own, specifically designed for autonomous ships. To avoid a framework which is detached from the rules that apply to other ships, or one that requires a separate ratification process with all delays that entails, a solution would be the development of a new SOLAS chapter, complemented by associated codes that spell out the requirements in more detail.
The Code(s) could also address the amendment of other IMO conventions, while the relationship to other SOLAS chapters would be clarified in the new Chapter. Inspiration may be drawn from regulatory solutions used in SOLAS Chapter XIV and the associated Polar Code.

3.8 Elements of an administrative framework for MASS

Despite the regulatory steps that have been taken by Finland to permit the authorization of MASS trials, there is no framework in place for organizing the authorization process or the permits for MASS in general. It follows from the IMO and national rules, that exceptions to traditional operation are to be granted by the competent authority, Traficom, as specifically acknowledged in both section 13a of the Act 1687/2009 and section 16a of the Pilotage Act (940/2003). Yet, there is little guidance on how this administrative process is to be undertaken, as well as on the criteria and procedures forming the basis of it. While this is not a report aimed at designing an administrative permit framework for authorities, a few preliminary reflections on administrative issues seem justified on the basis of the above review of the regulatory framework.

First of all, it appears that certain differences exist between rules concerning technical standards for ships' construction, design and equipment, and more operationally oriented rules. The existing rules concerning technical standards, notably those laid down in the SOLAS and Load Lines Conventions, include a well-established system of approving exceptions, alternative designs and equivalent solutions. The system has been in use by IMO for many decades, and its role is likely to expand with a gradual shift towards an increased use of goal-based standards. Such arrangements are permanent in nature and involve a communication of the national decisions to the IMO, which makes the information available to all members and observers to the Organization. As far as alternative design is concerned, there is an agreed procedure for the purpose, which takes departure in an application by the ship operator which is assessed and eventually approved by the administration. In reality the approval process is a complex dialogue between the owner and the administration, as outlined in IMO Document MSC.1/Circ. 1455. A procedure for approving alternative design and arrangements under SOLAS Chapters II-1 and III is laid down in MSC.1/Circ.1212. The procedure could usefully form a basis for the approval of technical construction and equipment requirement for MASS. The Norwegian guidelines, which establish a simplified procedure for approving MASS design, represent an interesting model for the purpose, bearing in mind the special requirements of software approval discussed below.

By contrast, a corresponding regime of exceptions is significantly less developed with respect to operational requirements. Some exception possibilities exist in SOLAS Chapter V, in particular for near-coastal trade, but the general tendency is that rules that regulate human behaviour on board ships, including the COLREGs, apply to a very broad range of ships and include limited scope for exceptions. This is despite the fact that operational conditions may well be of relevance only for a limited period of time, which could make temporal exceptions attractive in this field.

Among existing procedures, the assessment of safe manning seems most relevant for addressing operational matters on board. This ship-by-ship process is well regulated in both international and national law and includes a holistic overview of all functions required to be performed on the ship in question, as well as an assessment of whether those are met. This procedure could serve as the centrepiece for the assessment of the operational aspects of MASS, and probably without much modification. Rather, it seems that it is the criteria on which the assessment is based, in particular with respect to how technology solutions may assume duties traditionally performed by humans, that need to be adjusted in the case of MASS.

Similarly, the current safety management procedure, as regulated in the ISM Code and SOLAS Chapter IX, will retain a crucial role in the management on safety for MASS. The regulatory system and process in place work well, without particular need for amendment, but the manner in which the procedures operate, e.g. on the communication between ship and shore, will obviously have to undergo significant alterations in the process.

Finally, a new procedure needs to be developed with respect to authorities approving MASS trials in Finnish coastal waters. This process needs to deal with a series of concerns, in addition to the typical 'flag state issues', that are involved in the two other approval processes discussed above. This includes issues relating to the suitability of the area in question, the safety of other ships and the environment, and the availability of various supporting infrastructure etc. There is no existing precedent for this procedure, but the

IMO Interim Guidelines represent a first draft, and it is understood that the EU also is engaged in preparing (non-binding) guidelines on the matter.

In the longer run, however, the regulatory framework for MASS needs to look beyond existing legal rules and procedures. Replacing ship's crews by technology represents such a fundamental shift in how ships are operated, that it calls for entirely new rules to guide shipowners, technology developers, authorities and others to achieve the required level of safety. New standards are at least likely to be needed in the fields of standards for situational awareness generation and navigational planning by autonomous navigation systems, and connectivity between MASS and shore-based entities. In view of the close link between these rules and technology development, the new rules should be functionally oriented, neutral in terms of technological solutions, and adaptive to accommodate technological advancements. New rules will also call for new approval and certification processes. For example, as opposed to a ship's physical construction and design, software components used on MASS may change repeatedly, resulting in potentially significant changes to the ship's performance. Similarly, software bugs and cyber vulnerabilities, which may be detected during use, can affect the ship's perceived risk profiles fundamentally. This raises the need for authorities to develop processes for approving software updates, and, in case of failures, for monitoring software performance and potentially revoking approvals in case safety-critical problems are detected. The aviation industry safety programs could provide a template for these issues.

In addition, the existing civil liability regime for shipping may need to be reviewed if MASS will become more prominent in our waters. While the present regime might be capable of absorbing the alterations that MASS entails in the short run (given that the key subjects of liability, such as the reder, will remain in place), the proliferation of algorithmic decision-making fits uneasily with the current standard regime of liability, which is based on the assumption that errors or negligence have been committed by humans immediately involved in operating ships.

An increased role of new players, such as software developers and equipment manufacturers, in the operation of ships will also raise the prospect of new liability regimes, such as product liability, supplementing the maritime liability framework. These longer-term questions are considered in more detail in the next part.

Table 5 below is an effort to summarize the above procedures and measures that need to be established, and provide some examples of the elements that they could entail.

Table 5. Administrative Procedures and measures

Aspect of MASS	Process	Issues		Key elements (examples)
Construction & design	Approval by authorities	Application (ship operator)	Preliminary design/ final design	Determination of rules not complied with by the proposal and the reasons for it Determination of safety performance criteria for existing rules Detailed description of the alternative proposal, including the assumptions underlying it Demonstration that the alternative design and arrangements meet the applicable safety performance criteria. Risk assessment based on identification of the potential faults and hazards associated with the proposal (Hazid)
		Assessment (administration)		Safety level Close involvement throughout process Redundancy/complementarity 'Last risk condition' & 'Fail to Safe' solutions
	Certification		Certification body Third party verification	Trading area Conditions / limitations
	Test requirements			Real-life tests Role of simulation
	Procedure	Alt. design, exemptions & equivalents		Based on MSC.1/Circ. 1455
Operations	Manning		Functions to be performed	Based on safe manning (SOLAS Reg. V/14), Guidelines
	Safety management		Adaptability, Communication with stakeholders	Based on ISM Code (SOLAS Chapter IX)
Trials	Approval by authorities (new procedure)	Application	Required content	Area (extent, traffic conditions) Description of trial (ship, autonomy level, infrastructure needs, contact point...) Risk assessment Monitoring & management of trial Responsible person (w/ power to stop trial) Communication to stakeholders Information sharing
		Assessment	Principles	COLREGS compliant As safe as conventional ships
Future rule-development	Amending existing rules	Convention amendments	Conflict avoidance	STCW Ch VIII, + Code
			Clarification	COLREGs, SOLAS Ch V, XI-2 (ISPS) etc.
		Soft law solutions	Interpretations Guidelines	Role of master Safe manning Documentation etc.
	Developing new rules	Situational awareness	Overarching framework (New SOLAS Chapter?) Supplementary Codes	Goal-based, functional requirements Performance Requirements
		Autonomous decision-making		
		Communications		
		Other		

3.9 Next steps

On the basis of the above, a distinction is to be made between the regulatory steps required to get started with, on the one hand, MASS trials and, on the other hand, more permanent MASS operations. As for trials, the main regulatory building blocks for authorising trials are already in place, both nationally and internationally. It is therefore approval and verification processes that are needed for the authorization of such trial, rather than regulatory change. Some basic elements of that administrative framework at national level, and some IMO precedents on which to draw upon when designing it, were outlined in the previous section (3.8).

With respect to permanent MASS operations, legal intervention is required, both nationally and internationally. With respect to domestic operations, changes in national laws will suffice, at least for lower the levels of autonomy where a human is in charge of the operation. The main laws that need to be amended are the Crew Act (1687/2009), in particular the same provisions that are available for exemption by – and enumerated in - section 13a of the Act, and the Maritime Code, Chapter 6.

At international level, focus should shift from a 'backward-looking' regulatory scoping exercise to a forward-looking process of making new rules. The most important amendments are those that remove legal obstacles to MASS, which mainly are the physical presence requirements in the watchkeeping parts of the STCW Convention and probably also the rules on situational awareness in COLREGs and SOLAS. In order to achieve a 'top down' approach to the regulatory process, it is probably advisable to develop in parallel the general legal framework for MASS. This framework, it has been proposed above, should be introduced in the form of a new Chapter to SOLAS. The new chapter could be generic and outline the main goals and the relationship to other chapters, while more detailed rules and amendments of other instruments would be based on underlying instruments such as codes and, where necessary supplemented by guidelines and more detailed performance requirements. A (simpler) model for how the process could be designed can be found in the development of the Polar Code and the new SOLAS Chapter XIV.

Once the fundamentals of that overarching framework is agreed, but before it is adopted and in force, attention should be given to the new standards that will be required for MASS. Three such issues have been singled out as being particularly important and could represent separate codes under the new SOLAS chapter: machine-based situational awareness; computer-based decision-making in navigation; and requirements on ship-source communication and its failure. There will probably be a need for many more such codes and instruments over time, e.g. for matters relating to cybersecurity, ship-port interfaces, standards for remote operation centres and their staff, training requirements for MASS operators, liability rules or guidelines etc. But not all of these have to be in place before the operation of MASS can commence.

The new international regulatory framework for MASS will be a long-term process and it is not even foreseeable what aspects will eventually have to be in it. As a guiding principle, rules should be goal-oriented, establishing functional requirements rather than technical prescriptive requirements in order to ensure that they are technology neutral and have a relevance which extends beyond a certain technical solution in a fast-developing field.

4 A future regulatory framework

4.1 Charting a future regulatory framework

Chapter 4 discusses the design parameters and constraint of the future regulatory framework for governing commercial and large-scale MASS deployments in the medium-term future, once the initial testing and piloting phase has been completed. The report envisions that regulatory framework should primarily coalesce within the auspices of the IMO rule-making procedures, buttressed by some national legislative action.

To set the scene, the chapter commences with a discussion of the ethical framework in which MASSs should be positioned. As the core novelty of MASSs lies in their reliance on algorithmic decision-making, the chapter argues that the ethical framework is one of algorithmic ethics. The chapter then discusses algorithmic ethics and identifies safety as the priority ethical concern in MASSs, without disregarding other concerns. As navigation is the most important safety-critical function to undergo a radical transformation in transition to MASSs, the chapter moves on to identify and discuss the ethical flash points of technology-mediated navigation and the role that algorithmic transparency may play as an ethical regulation tool. The ethics part is rounded out by a short excursus into ethical design processes.

After establishing the ethical corner stones for MASS regulation, the chapter moves to discuss the future MASS regulatory framework. *Regulatory standards, ensuring that autonomous navigation systems (ANS) are capable of navigating the ships safely, constitute the bedrock of the regulatory framework* on which all MASS regulation will and must build. The chapter outlines the regulatory landscape, sets out the various regulatory options, and discusses their strengths and weaknesses. Ultimately, the chapter arrives at a recommended structure for the future ANS regulatory framework.

After outlining the regulatory framework for autonomous navigation systems, the chapter discusses *a selection of other regulatory issues*. The chapter, first, discusses how shore control centres on RO-MASSs should be regulated. SCC regulation should cover both the physical and technological composition of SCCs, and the regulation of SCC staff. Third, the chapter discusses how MASS should behave when experiencing connectivity breakdowns and ending up in too challenging operation domains. Fourth, the chapter makes a short excursus into cyber security issues, arguing that the high risks involved in MASS activities requires strong cyber security regulation. Fifth, the chapter explores how communications with external parties, such as Vessel Traffic Service (VTS) operators and other ships, should be organized.

After discussing the selected regulatory issues, the chapter moves to discuss *liability and accountability in MASS contexts*. The chapter outlines the current liability regime for MSS traffic and reflects on what changes MASS introduction may trigger. The discussion centres on non-contractual liability rules, including product liability rules, but also discusses the pressures that MASS introduction may impose on shipbuilding and ship operation contracts.

Finally, the chapter addresses data and infrastructure related issues. The chapter, first, argues that data regulation may introduce important constraint, which seems likely to add uncertainty to MASS development and deployments. Second, the Chapter argues that regulators should explore regulatory options to encourage and mandate data sharing. Third, the chapter argues that the regulatory framework may have to be buttressed by an infrastructure layer aiming at making the MASS operational environment MASS friendly. The infrastructure measures could range from expanding the scope of the obligation to carry AIS transponders and radar reflectors and introducing a new obligation to carry MASS compatible communication equipment, to reforming VTS services provision.

4.2 MASS Ethics

4.2.1 Introduction

In recent years, ethics has emerged as an important practical and research topic in AI and robotics. Tens of ethical AI principle collections have sprouted up (Jobin, Ienca, and Vayena 2019). Thousands of articles have been written on the topic. Transparency is similarly a central topic in AI and robotic contexts. (Coeckelbergh 2020; Turner 2019; Dignum 2019; Lin, Abney, and Jenkins 2017; Wallach and Asaro 2020)

This section of the report, first, delineates the space for MASS ethics and argues that safety should be considered the primary ethical framing of MASS ethics. The increasing reliance on navigational technologies in MASS will result in a fundamental change in maritime risk patterns. Technological navigation will, thus, constitute the most important domain for ethical analysis and design in MASSs. Consequently, the report will, second, identify the main focal points of MASS navigational ethics and discuss the regulatory implications of the ethical concerns within navigation. Third, the report deals with the promise transparency holds as a regulatory device in ensuring ethically sustainable MASSs. Fourth, the report concentrates on how regulators can exercise control over and influence ethical decisions in MASS navigational system design processes.

4.2.2 MASS ethics concerns

4.2.2.1 Algorithmic ethics

In the following, the report will delineate the space of MASS ethics. The distinctive feature of MASSs is that the ships will rely on algorithmic decision-making. This is their novelty compared to traditional MSSs. Instead of humans at the helm, algorithms will navigate the ship. Consequently, MASS ethics is primarily applied algorithmic ethics.

> MASS ethics is applied algorithmic ethics.

As MASS ethics is algorithmic ethics, the starting point for the delineation exercise is provided by an influential paper by Mittelstadt et al. (2016) on algorithmic ethics. The paper, importantly, identifies six ethical concerns that arise in algorithmic decision-making contexts.

The concerns are:

1) As many algorithmic systems have machine learning and statistical components, algorithms may, first, make decisions upon inconclusive evidence.
2) The algorithms may also be inscrutable, arising out of statistical data analysis that defies human narrative explanations and, thus, will result in inexplicable decisions.
3) The data used in developing the algorithms may be also wrong, giving rise to the garbage-in-garbage-out effect.
4) Even if the data used to train the algorithms were correct, give conclusive evidence of narratable patterns, the consequences of using the algorithms may be unfair, that is affect shareholder interests in unacceptable ways.
5) AI and algorithms will have transformative effects on our societies, changing existing structures and interaction patterns.
6) Algorithmic systems will, finally, decrease the traceability of action by providing an additional layer between human action and its consequences, confusing causation and correlation. This will negatively affect our ability to impose accountability for algorithmic action.

Mittelstadt et al's concerns retrace the issues identified in *e.g.* the OECD AI Recommendations (OECD 2019). Importantly, they also seem to underlie many of the themes addressed in the EU AI White Paper (European Commission 2020).

> The primary concerns of algorithmic ethics relate to inconclusive evidence in data, inscrutability of algorithmic decision-making, worries over defective data, fairness, the transformative effects of AI technologies, and the effects AI technologies have on traceability and accountability.

Mittelstadt et al's list of concerns is, of course, not exhaustive. Other scholars have added to the list of ethical concerns. For example, Nick Bostrom among others has pointed out that AI may at some point lead to the emergence of new kind of actors if AI develops capabilities that surpass human intelligence. This may have disastrous consequences for entire societies (Bostrom 2014). On a more modest plane, artificial intelligence triggers concerns over moral agency and patiency. If and when artificial agents develop to gain new capabilities, we may have to question whether we should treat as having moral agency or, at least, patiency, and, thus, worthy of respect (Gunkel 2017).

4.2.2.2 Identifying specific algorithmic ethics concerns in MASSs

While all the concerns identified by Mittelstadt et al are potentially important in MASS contexts, the unique features of the robotic context and the technological solutions MASSs will likely adopt should be taken into account.

First, MASS ethical concerns vary from one design decision frame to another. Consequently, there can be no single framework for MASS ethical analysis. For example, deciding whether MASS development or commercial deployments should be pursued in the first or how particular technological systems should be designed involve drastically different sets of ethical concerns and require highly specific and detailed situational analyses that take into account the varying frames of ethical decision-making.

> MASS ethical analysis should be understood as a situational and layered practice.

Second, while we should have a profound discussion on whether introducing MASSs is ethically desirable in the light of the technologies' transformative effects, this report assumes that the decision is already made and MASSs will be allowed to trade. Thus, the frame for delineating the space of MASS ethics is one where MASSs can be and are presumed to someday exist. This starting point conditions the following discussion. The discussion, consequently, focuses on making sure that MASS designs are ethically sustainable.

Third, the data related concerns are attenuated by the characteristics of MASS development processes. Most MASS algorithms do not rely on drawing statistical inferences after analysis of massive amounts of data, but contain traditional rule-based code. This means that many of the hyped ethical concerns that arise out of the Big Data methodologies underlying some algorithms will likely have a limited impacting MASS contexts. For traditional code, inconclusive evidence, inscrutability, and wrong data inputs are mostly irrelevant concerns.

Even where MASS algorithms may be by marred by inconclusive evidence, inscrutability, and the effects of defective data inputs, effective mitigation methodologies are available. It is important to note that currently only some algorithms used to spatial and semantic signal processing and target vessel trajectory modelling contain algorithmic components that build on statistical data analysis. Even here, the processes differ from those typically contemplated in the algorithmic ethics literature. First, all of the processes have definable "right answers": designers can define what the desirable spatial and semantic signal processing outcomes and target vessel trajectories are. The knowability of end states allows for performance verification and transforms the ethical challenges to resemble those encountered in traditional code contexts. Consequently, inconclusive evidence, inscrutability, and wrong data concerns are relatively subdued in MASSs. The problems can be effectively mitigated using sophisticated and comprehensive testing.

> Inconclusive evidence, inscrutability, defective data inputs are subsidiary concerns in MASS contexts.

Consequently, the fairness of MASS outcomes rises in prominence as an ethical concern.

> Fairness is the primary ethical concern in MASSs.

While safety is explicitly nowhere to be found in Mittelstadt's list, the neglect is illusory. Safety is a fairness concern: in a fair world, MASSs should not inflict unfair harms. The report argues that safety should be the primary ethical concern for MASSs, if and when the transformative effects of MASS development and deployment are eliminated from the scope of the analysis.

However, safety as a notion in itself is devoid of meaning. It has to be defined. Defining safety, in turn, is a process rife with ethical choices. MASS regulators should weigh in on the process and not leave it to industry actors only. The report argues that preventing the risk of loss of human lives and bodily injuries should be a first order design concern with property and environmental interests following as second order concerns. The ships should be, consequently, designed to impose an acceptably low level of risks to life and limb, environmental interests, and property interests. What the level of acceptable of risk and in what terms risk levels should be conceptualized are, similarly, important ethical questions.

> MASS designs should minimize risks to life and limb, environmental interests and property.

The transformative effects of MASSs also deserve scrutiny. However, the report does not discuss these issues. Simultaneously, one should note that many ethical concerns identified for social and assistive robotics are not relevant in MASS contexts. It is highly unlikely that MASSs will replace human contact in anyone's social life or become significant companions to frail human beings to whom the humans develop emotional ties.

MASS ethics concerns are summarized in Table 6 below.

Table 6. MASS ethics concerns.

Concerns (Mittelstadt et al 2016)	General frame	Frame in MASS contexts	Regulatory significance
Inconclusive evidence of causation	Some machine learning methodologies may detect correlations but fail to demonstrate causation.	N/A.	If relevant, can be mitigated by testing.
Inscrutable algorithms	Some machine learning methodologies may result in incomprehensible algorithms.	How semantic signal processing or sensor fusion algorithms reach decisions cannot be explained.	Inevitable, in part, but as "right" outcomes are knowable, mitigatable by testing.
Bad or wrong data	Data may be wrong and result in garbage-in-garbage-out effects	Camera training data may be mislabelled.	Mitigatable by testing.
Fairness of algorithmic outcomes	Outcomes may be biased or otherwise unfair.	MASSs may inflict personal injuries or property losses on third parties.	MASSs may cause significant, possibly catastrophic losses on third parties. High regulatory priority.
Transformative effects	Use of algorithms may trigger changes in our social environment.	MASSs may make mariners unemployed.	MASSs may have significant transformative potential. However, outside scope.
Traceability	Algorithms may complicate pursuing accountability by hiding decision-makers.	Allocating responsibility for those who caused accidents may become difficult.	Mitigatable by stringent preventive regulation.

4.2.3 Navigational ethics flash points

4.2.3.1 Introduction

MASSs will increasingly rely on technological systems for navigation. This will constitute the fundamental change in maritime risk patterns. Immediate human errors and negligence in navigation, an important root cause for many maritime accidents, will be eliminated to the degree autonomous navigation systems are involved in navigation with navigational safety risks increasingly transforming from human risks into technological risks. As a result, technology-mediated navigation will constitute the most important domain for ethical analysis and design in MASSs.

> Navigational technology designs are the ethical focal point in MASSs.

The report will, in the following, identity and discuss five ethical flash points:

1) the general level of risk at which MASSs should be allowed,
2) the ethical questions that arise when sensory capabilities are designed,
3) the ethics of operational ontologies in semantic signal processing,
4) uncertainty management, and
5) the ethics of path planning.

4.2.3.2 Safer than MSSs?

Whether technology-reliant navigational processes should be allowed at all, is the first flash point of navigational ethics. The decision frame appears relatively simple to delineate in a safety-oriented ethical analysis. MASSs should be allowed only if they impose smaller safety risks than MSSs as increasing risks to allow the pursuit of increased profits is an untenable ethical conclusion.

The framing may, however, be deceptive in its simplicity. The reason is that the nature of MASS and MSS navigational risks differ fundamentally. MASS risks will likely be systemic and highly correlated across vessels, while MSS risks are more randomly distributed. The accident characteristics could also be different.

The differences in risk dynamics and profiles may result in apples to oranges comparisons and a distorted framing of the ethical trade-off. For example, even if risk analyses would indicate that MASSs would likely be safer than MSSs on the average over long time periods, allowing MASS introduction would require that we tolerate the risk of temporally highly concentrated accident clusters that are, in turn, extremely unlikely to take place in MSS contexts. The report, thus, argues that there may be no simple universal metric for assessing the level of risks MASSs impose relative to MSS risk levels. Any risk level trade-offs contain an ethical component as the decision makers have to appraise what significance should be accorded to the differences in the risk profiles.

> Risk profile differences should be mapped and considered in comparing MASS and MSS safety levels.

4.2.3.3 Sensor ethics

Sensors constitute the second ethical flash point as sensory capabilities significantly affect the MASS safety level. To illustrate how, imagine a road ferry operating in a densely populated archipelago. The ferry could, conceivably, cross paths with a swimmer. Should the ferry have a sensory capability to detect swimmers in time to evade them?

Significant ethical choices are made when designers configure MASS sensory setups. Sensor configurations condition what objects MASSs can detect, over what distances and under what conditions, determining the outer boundaries of the MASS operational ontology. If a MASS lacks a capability to detect an object, the object does not exist in the ship's universe, and, importantly, the ship will have no capability to act in relation to the object.

> Sensor configuration decisions are rife with ethical choices.

The decision to include in or exclude from the scope of relevant objects is, thus, of utmost ethical consequence. The object that exists in the real world but that the ship is incapable of detecting are rendered ethically worthless. Sensory capabilities, consequently, determine in part what objects exist for the ships, that is their operational ontologies. The operational ontologies prime the ships to act and determine the objects in relation to which the ship can act.

> Sensory capabilities condition what operational ontologies are available to a MASS.

Thus, while sensory setup configuration decisions are likely often dominated by pragmatic considerations such as availability and costs of various sensors, the MASSs operational design ontologies and, upstream, sensor setup configurations are crucial pieces of the MASS ethical puzzle. As MASSs may impose significant risks to important safety interests, regulators should take an active role in guiding their development.

Two considerations should be born in mind when making decisions on how to regulate sensor configurations. First, mapping existing human sensory capabilities and requiring that MASSs have at the minimum an equivalent capability could arguably provide an ethically feasible standard for regulators to impose. The report, however, points out that human senses and technology sensory systems have different strengths and weakness. Imposing a human equivalent performance standard would fail to mandate that developers leverage the strengths of the technological systems and, thus, will likely lead to suboptimal outcomes.

> Imposing a human-equivalent requirement for sensory capability fails to leverage technology strengths.

Second, technological difficulties in or costs of building a sensory capability should not be given undue weight in the regulatory deliberations. Investments in R&D are often guided by regulation. If the regulators set standards that do not push the boundaries of the possible, firms may be reluctant to invest in development work that is unlikely to bear direct financial benefits. Consequently, regulators should 1) issue rules on what objects MASSs must, at a minimum, detect, and 2) articulate standards for minimum detection capabilities. The standards should take into account the vessel type and its operational design domain.

> Operational ontologies should be regulated by binding rules.

In addition, the report recommends that manufacturers be required to 1) document the objects the sensory system has been configured to detect as well as the objects that the manufacturer is aware the system will not be able detect, and 2) motivate the decisions to include and exclude objects, and 3) subject the original MASS sensory configuration and all updates to it to an ethical review by an acceptable ethics review body. Submitting acceptable documentation should be a precondition for regulatory approval.

> Operational ontology related choices should be documented and motivated.

4.2.3.4 Semantic ontologies

The next navigational ethics flashpoint emerges inside semantic signal processing. Semantic signal processing employs computer vision methodologies that transform visual data feeds into object labels, i.e. identify objects in the ship's environment.

The semantic signal processing algorithms will likely derive from supervised machine learning processes. The algorithms will be trained using curated human-labelled picture data from the MASS operational design domains. In practice, human workers will label each training dataset image with a label that "tells" what the object is. The labels, consequently, constitute a crucial navigation ethics flash point.

The semantic signal processing algorithms, when in use, will produce worlds that consist of the objects someone identified when the roster of possible object labels was put together. The roster of training dataset labels constitutes a listing of the possible objects the ships may encounter and identify. What exists on the list, exists in the world. What does not exist on the list, does not exist (Crawford and Paglen n.d.).

The ethical stakes are high as the semantic mapping outcomes condition the both the ethical decision-making available in upstream navigational processes, such as uncertainty management and route planning.

To illustrate how labelling decisions frame downstream navigational decisions, consider the previous swimmer example. If the semantic signal processing algorithms have no "swimmer" or "human" labels, the upstream navigational processes cannot be even made to act in relation to swimmers or humans. There simply is no possibility for building a capability to evade swimmers or floating humans because there are no swimmers or humans in the MASS operational ontology.

Here, manufacturer interests may not be aligned to support ethically sustainable systems. There is typically a trade-off between system complexity, costs and the level of detail in information extracted from sensors. Even the COLREG rules specify many requirements for watch keeping which require dedicated models or subsystems, such as detecting and identifying alarm sounds (horns, gongs, gunshots), flag signals, signal lights, etc., driving up system development costs.

As with sensory system configuration, regulators should issue rules on what objects MASS semantic mapping algorithms must, at a minimum, detect. The standards should consider the vessel type and its operational design domain.

> Semantic ontologies should be regulated by binding rules.

In addition, the report recommends that manufacturers be required to 1) document the objects the semantic mapping algorithms have been trained to detect, and 2) motivate the decisions to include and exclude objects, and 3) subject the original MASS semantic signal processing algorithms and all updates to them to an ethical review by an acceptable ethics review body. Submitting acceptable documentation should be a precondition for regulatory approval.

> Semantic ontology related choices should be documented and motivated.

4.2.3.5 Managing uncertainty

The fourth ethical flash point relates to managing uncertainty within sensor fusion processes. The spatial and semantic maps MASSs produce are probabilistic representations of the world. Object classifications are uncertain estimates of what the objects the ship has detected, in fact, are. Similarly, spatial information is marred by uncertainties.

To illustrate: imagine that a MASS detects a small floating object. The object classification algorithms could originally classify the object a leisure craft but seconds later reclassify it an unknown object. Both classifications contain uncertainty. Even if the developers built an algorithm to quantify the uncertainty, it will remain. Simultaneously, the ship should choose a course of action despite the uncertainties.

This may involve trade-offs between safety and smooth navigation, since accepting object detections with low prediction confidence may cause false positive detections leading in unnecessary collision avoidance, while high confidence thresholds may cause real hazards to be ignored, compromising navigational safety.

> Developing methods for managing uncertainty in situational awareness necessitates careful ethical analyses.

To reduce this risk, it is important to ensure that data used in model training and system testing has sufficient coverage of real-world scenarios, and that all models are well trained and tested. In addition, the development processes should incorporate comprehensive ethical analyses of various design trade-offs.

> Regulators should require that ANS developers document all relevant design choices.

4.2.3.6 Path planning and collision avoidance

Path planning and collision avoidance processes constitute the fifth ethical flash point. Ethical trade-offs and controversies permeate the algorithms. However, the particular technological approaches designers choose may significantly affect what ethical controversies instantiate.

4.2.3.6.1 Design philosophy and risk appetite

A persistent controversy arises as expeditious execution of the voyage plan and safety will become contradictory objectives in path planning processes. This may happen, for example, when the MASS detects a moving object. The dynamics create an uncertainty which the MASS algorithms must take into account when adjusting its course and speed. Decreasing the speed and giving the object space will likely increase both voyage time and bunker fuel costs yet decrease the likelihood of a collision. In algorithmic systems, code has to be drafted to accommodate these trade-offs. The code will, inevitably, reflect and perform the ethical preferences of its designers.

The issue has been recognized in several documents dealing with ethical robot design. The German automotive industry Ethics Commission arrived at the following ethical principle:

> "Automated and connected technology should prevent accidents wherever this is practically possible. Based on the state of the art, the technology must be designed in such a way that critical situations do not arise in the first place."

The key message of the Commission was that vehicle designs should aim making sure that the vehicles not end up in a position where accidents are inevitable. The same principle should guide MASS design processes as well. The MASS environment and its inherent risks lend additional importance to a precautionary approach as the damage that could result from a large scale MASS accident is potentially catastrophic.

> The path planning algorithms should be built to minimize the risk of collisions and other accidents. MASSs should configured to take all possible preventative measures to avoid collisions. MASS ANSs should be designed to minimize the risk of collisions.

4.2.3.6.2 Trolley problems

Sometimes collisions and other safety events will, nevertheless, be inevitable. These situations present often what are known as trolley problems (Wu 2020, 4). As encountering a trolley problem signifies a risk management failure (Goodall 2016), the primary design principle should be that MASSs be configured to take all possible measures to avoid collisions.

> MASS ANSs should be designed to minimize the risk of encountering trolley problem events.

Developing approaches for managing choices between bad outcomes is a process that should be permeated by ethical analysis. Trade-offs between subjecting human lives, property, and environmental interests in jeopardy will likely have to be made. The difficulties will likely be compounded by the high stakes of shipping accidents. Ships are capable of inflicting catastrophic losses and gravely damaging important non-pecuniary interests. Thus, designing solution to trolley problems requires thorough ethical analyses. Regulators should articulate high-level principles for MASS behaviour in trolley problem events.

> Developing feasible solutions to trolley problems requires thorough ethical analyses and interventions by regulators.

In systems that use potential field type path search algorithms, trolley problems often translate into questions on what values should be set for various objects to make them either attractive or repulsive within the search algorithms.

The sophisticated trolley problems one often encounters in popular media accounts may, however, be rare in practice. Sensory data will likely be insufficiently granular to allow finely tuned decision-making frames.

MASS ethics flash points are summarized in Table 7 below.

Table 7. Table 7: MASS Ethics flash points.

Ethics flashpoint	Ethical frame	Solutions	Stakes	Regulatory options
When to allow MASSs?	How safe should MASSs be?	Develop metrics to compare MASSs to MSSs.	Lives, environmental and property interests.	Articulate metrics for assessing MASS safety.
Sensor systems	What objects should MASSs be capable of detect?	Develop minimum regulatory operational design ontologies.	Lives, environmental and property interests.	Set minimum standards for sensor system performance.
Semantic signal processing	What objects should MASSs be capable of detecting?	Develop minimum regulatory operational design ontologies.	Lives, environmental and property interests.	Articulate minimum regulatory operational design ontologies
Managing uncertainty in sensor fusion	How certain should MASSs be of the objects they detect?	Develop methods to manage tradeoffs b/n speed and safety.	Lives, environmental and property interests.	Draft regulatory guidelines. Require documentation and justification.
Trolley problems	Who or what should a MASS sacrifice if an accident can't be averted?	Develop ethical guidelines for designing code to solve trolley problems.	Lives, environmental and property interests.	Draft regulatory guidelines. Require documentation and justification.
Risk appetite	How aggressive should a MASS be in its navigational decisions?	Develop ethical guidelines for designing algorithms.	Lives, environmental and property interests.	Draft regulatory guidelines. Require documentation and justification.

4.2.4 Transparency and explainability

4.2.4.1 Introduction

Algorithmic systems may, at worst, be inscrutable and incomprehensible black boxes closed by trade secrets and cryptography and impervious to attempts to understand them. Transparency and explainability are often hailed as panacea to algorithmic decision-making woes in the AI ethics literature.

> Transparency is often hailed as a panacea and conducive to better algorithmic decisions.

The argument is that if the black boxes are transparent, bad outcomes will be less likely than in non-transparent and opaque systems. The report argues that the promise of transparency may be overblown, in particular for MASS type robotic systems.

4.2.4.2 Types of transparency

To facilitate further discussion, note that transparency comes in multiple flavours. Algorithmic systems can be transparent *ex ante* or *ex post*, and the transparency measures may target multiple audiences. Further, explainability is an important dimension of transparency.

4.2.4.2.1 Ex ante transparency

Ex ante transparency measures require that algorithm developers disclose meaningful information on algorithms before any adverse incident has taken place.

> Ex ante transparency requires disclosures prior to adverse events.

Ex ante transparency measures may serve two purposes. They may, first, increase the legitimacy of algorithmic systems, boosting their trustworthiness as the subjects of algorithmic decision-making and other stakeholders gain visibility into how and on what grounds the decisions are made. It also affords contestability. If the reasons justifying decision-making are known, stakeholders feeling that they have been treated unjustly, may fare better in pursuing remedies. Second, *ex ante* transparency may offer developers an avenue for interaction with external stakeholders, allowing them to engage in collaborative design. Designers may get gain outside input and perspectives into the design processes. In this sense, *ex ante* transparency may, third, also be deployed as a regulatory instrument. Requiring transparency could facilitate processes that ultimately weed out undesirable MASS designs as the stakeholders engage with and exert influence on the developers.

4.2.4.2.2 Ex post transparency

Ex post transparency measures, instead, entails that developers to disclose meaningful information on the algorithms after an adverse incident has taken place.

> Ex post transparency kicks in after adverse events.

Ex post transparency may serve three purposes. First, it will likely be necessary to allow investigators and, ultimately, the public to reach an understanding on what happened and why. Without visibility into how decisions are made, algorithmic action cannot be explained. Second, *ex post* transparency is important for establishing accountability for adverse outcomes, allowing both authorities and private parties to enforce consequences for bad design choices. *Ex post* transparency may, third, also have regulatory effects. On the one hand, awareness of possible future transparency-mediated accountability may affect design choices. On the other hand, the accountability processes, such as liability trials, may create *ex ante* rules that constrain design choices in the future.

4.2.4.3 Transparency audiences

To serve its purposes, transparency needs an audience. Crucially, different types of transparency need different audiences.

> Transparency needs an audience to have an effect.

Ex ante transparency towards the general public may enhance the public's perception of MASS legitimacy and trustworthiness. The regulatory use of *ex ante* transparency, instead, needs particular audiences: the audience has to be able to understand the communications and willing and able to contribute constructively in the design processes.

Ex post transparency may be directed to multiple audiences as well. *Ex post* transparency aimed at the general public will have mostly have attitudinal effects. Authorities, in turn, will need *ex post* transparency when investigating accidents and appraising future administrative or legislative measures. Aggrieved parties will similarly need access to information to pursue for example damages claims.

4.2.4.4 Explainability

Explainability is an extension of algorithmic transparency. The thinking is that mere transparency is not always sufficient. The problem underlying calls for explainability in addition to transparency stems from the technical character of machine learning based algorithms. Machine learning system developers often use ultimately statistical data analysis methodologies to develop algorithms capable of performing specific tasks. These methodologies are *correlationist*: they associate certain patterns in training data with specific outcomes.

The resultant algorithms may be interpretable: humans may be able to identify what data patterns trigger specific results. However, the algorithms may simultaneously, defy human explanation attempts. Humans, with their fundamentally causational and conceptual sense making, cannot explain why and how the specific patterns came to be correlated with the specific outcomes. Consequently, machine learning based algorithms sometimes make decisions where humans cannot understand why the decision was made beyond explaining that the algorithm came to a conclusion based on the patterns and correlations it found in the training data.

In recent years, a lively discussion and considerable research activity has emerged around explainability of artificial intelligence, driven by the, at times regulation-induced, need to explain how algorithmic decision are made. Explainable algorithms are, of course, more trustworthy and legitimate than unexplainable, hence their appeal.

> Explainable AI (XAI) systems contains algorithms that can be explained to humans.

4.2.4.5 Transparency and explainability in MASSs

In the following, the report discusses transparency and explainability in MASS contexts in more detail arguing that transparency and explainability may have limited utility in MASS contexts.

4.2.4.5.1 Ex ante transparency in MASSs

First, *ex ante* transparency aimed at general public may serve to dispel apprehensive attitudes and increase trust in MASSs. The general public is, however, unlikely to be able to contribute to MASS development processes as such contribution requires significant resources and skills. Further, the technological nature of MASS algorithmic systems alleviates the need to institute wide-ranging transparency towards the general public. MASS performance and safety can be validated by using simple, verifiable performance metrics. The systems are either capable of navigating safely or not. Consequently, legitimacy and trustworthiness should primarily be created and sustained by safe performance, not explication of how the systems reach their decisions.

> MASS legitimacy and trustworthiness is best sustained by demonstrable safe performance, not by explications of how the systems reach their decisions.

In addition, the disclosure of detailed technical information on how the systems or algorithmic components work may be risky. The information may allow malevolent actors to harass MASSs. Regulators should undertake careful analyses of the consequences of transparency measures aimed at the general public. Nevertheless, requiring developers to disclose, at an appropriate abstract level of abstraction, how MASS make navigational decision and, in particular, how they treat different objects, is advisable.

Second, *ex ante* transparency aimed at stakeholders may have beneficial consequences, although it is marred by similar risks. Regulators should undertake careful analyses of the consequences of transparency measures aimed at external stakeholders.

> Ex ante transparency may be risky as it could facilitate gaming and harassment.

The report, however, recommends that regulators mandate wide-ranging transparency disclosures towards regulators and their delegates to facilitate risk assessment and approval process.

> *Ex ante* transparency towards regulators is key to effective risk assessment and approval processes.

4.2.4.5.2 Ex post transparency in MASSs

Ex post transparency serves an important purpose in producing accounts of adverse incidents and ensuring accountability. Consequently, ensuring ex post transparency is crucial, also in MASS contexts.

However, *ex post* authority-facing transparency already has an existing regulatory framework in the Safety Investigation Act (525/2011) and the related EU directives, the Criminal Investigation Act (805/2011) and the Coercive Measures Act (806/2011). Similarly, national rules on in-trial discovery provide claimants a limited right to obtain evidence from defendants.

> The accident and criminal investigation authorities seem to have sufficient rights to obtain information, but jurisdictional limits may hamper their work in crossborder investigations.

Rules on in-trial discovery are notoriously restrictive in Finland and could hamper aggrieved parties in their efforts to establish accountability for MASS accident. Regulators should work to enhance the regulatory framework for cooperation in marine accident investigation. Regulators should explore options to strengthen pre- and in-trial discovery rules in algorithmic contexts.

> Regulators should explore enhancing plaintiffs pre- and in-trial discovery rights for robotic contexts.

4.2.4.5.3 Explainability in MASSs

Explainability appears a subsidiary concern in MASSs. First, as pointed out earlier MASS safety performance can be validated by observational testing. This is true, in particular, for object classification algorithms and alleviates the pressures to provide explanations. On the other hand, forcing explainability on these algorithmic components could be counterproductive. Second, many ethically important algorithmic components such as path planning algorithms are at their core explainable.

> Explainability appears a subsidiary concern in MASS AI systems.

4.2.5 Ensuring ethical MASS designs

Above, the report has attempted to scope out the ethical pitfalls inherent in maritime autonomous surface ships and outlined possible avenues for regulation. In the following, the report makes a brief excursion into how ethical design processes could be achieved. The path goes, in part, through regulation.

4.2.5.1 Options

Two main options are available to both regulators and firms to ensure that AI design processes produce ethical outcomes: codes of conduct and ethical-by-design approaches.

4.2.5.2 Codes of conduct

The first option is to put in place codes of conduct or design principles. As recounted above, such principles have abounded in recent years. While AI as general technology has been at forefront in these principle, robotics, specifically, have received some attention as well (For a robotics-oriented principles document, see Boden et al. 2017).

Ethical codes of conduct and design principles may, at times, be effective tools. However, their effectiveness is constrained by their general outlook. If not backed up by either regulatory or intrafirm sanctions, the codes and principles act, in many respects, like sanctionless law. They may articulate lofty behavioural maxims, provide food for thought, remind their readers of important points of view, and serve as aspirational documents, but often fail to initiate or sustain concerted action inside organizations.

> Ethics principles and codes of conduct could fall short in inducing ethical design choices.

4.2.5.3 Ethics by design approaches

The other option is to engage in **ethics by design**. Ethics-by-design approaches seek to build organizational structures and cultures that embed ethical analysis and action in the very fabric of design organizations (Iphofen and Kritikos 2019; Dignum et al. 2018; Hatfield 2019). In regulatory theory, the approach is often referred to as management-based regulation (Coglianese and Lazer 2003; Parker 2002; Viljanen 2016). The best known regulatory example of how a by-design approach can be implemented can be found in the GDPR and its privacy by design initiative (Kamara 2017). In concrete terms, the ethics by design approach would entail that MASS technology developers build organizational bodies, competencies, and workflows that embed ethical analysis into its everyday practices.

> Ethics-by-design focuses on building organizational ethics competencies.

The firm might hire a chief ethics officer tasked with coordinating ethical assessments in the firm. The firm might also institute ethics review boards to act as internal deliberative bodies where difficult design decisions would be escalated. Each development team might be assigned an employee whose job it is to keep ethics at the forefront of everyday work. The firm might also establish workflows that ensure that all product development decisions undergo ethical assessments, draft and mandate ethics assessment checklists, and build ethical assessment tools or applications for its employees to use. Similarly, documentation requirements for important decisions and their underlying reasoning might be introduced.

While regulators are still to issue ethics by design guidelines, standardization bodies have started the work on various AI related process standards. (IEEE SA n.d.) Similarly, even if ethical principles and codes of conduct may have limited utility as regulatory tools in MASS contexts, managed-based regulation and process standardization hold more promise and should be explored as potential regulatory approaches within IMO.

> Ethics-by-design approaches will likely be efficient in inducing ethical design choices. Regulators should explore mandating ethics-by-design programs for ANS developers.

4.3 Standards for autonomous navigation systems

4.3.1 The regulatory challenge

4.3.1.1 Identifying starting points

In Chapter 3, the report identified a plethora of SOLAS and STCW rules that may be impacted by the introduction of MASS technologies. These rules relate to, for example, ship construction, fire protection, fire detection and fire extinction appliances, life-saving appliances and arrangements, radiocommunications, and navigation.

MASS introduction will undoubtedly require a comprehensive review of SOLAS and STCW rules. IMO should draft and publish a separate MASS SOLAS Chapter or introduce a MASS Code to address the revision needs and contain the future applicable rules for MASSs.

Navigation the most safety-critical of the processes MASS technologies will significantly affect. Once MASSs are introduced, autonomous navigation systems will replace crews and take over navigational duties. Ships will become increasingly and, ultimately, entirely reliant technology-mediated navigational processes. The transition will fundamentally transform ship risk profiles as navigational risk becomes technological in character. While MASS introduction will require new technical standards on, for example, ship-to-shore communications, SCC technologies and staffing, and cyber security, the most important of the part of the future MASS rule book will deal with what technologies can be used to perform the navigational function on MASSs. Correspondingly, regulations that address how Autonomous Navigation Systems (ANS) are built will constitute the bedrock on which all MASS regulation will build.

> As autonomous navigation systems will largely determine MASS risk profiles, regulating autonomous navigation systems should constitute the bedrock of MASS regulation.

Regulators should, thus, focus their work on developing an appropriate and effective regulatory framework for autonomous navigation systems. However, the new MASS-ready navigational regulation will unlikely resemble its predecessor. The previous SCTW and SOLAS navigation rules do little to make sure that MASS situational awareness and navigational planning systems, in fact, will navigate the ships safely. The previous rules were designed to control sociotechnical processes where humans made decisions based on informational inputs from both their own senses, other people's senses, and a variety of navigational aids. The new reality is high-tech, computerized, and dominated by algorithms.

Regulators should focus their work on developing an appropriate and effective regulatory framework for high-tech computerized autonomous navigation systems dominated by algorithms.

The report, consequently, focuses on discussing the standards that ensure that autonomous navigation systems are capable of navigating the ships safely

4.3.1.2 How is navigation regulated in MSSs?

To understand the scope of the regulatory challenge, consider the existing MSS navigational regulation complex. The rule complex consists of three components.

First, the rules in STCW Code Chapter VIII *regulate how humans* – the master, the Officer in Charge of Navigation, and crew members – *should perform when participating in navigational processes*. The rules target what navigational work is done and how it is organized (navigational workflows. The SCTW Code Section A-VIII Part 2 deals with voyage planning.

Voyage planning is the duty of the master. It comprises of planning "the intended route from the port of departure to the first port of call […] using adequate and appropriate charts and other nautical publications necessary for the intended voyage, containing accurate, complete and up-to-date information regarding those navigational limitations and hazards which are of a permanent or predictable nature, and which are relevant to the safe navigation of the ship".

The STCW Code Section A-VIII Part 3 and COLREGs Rule 5 regulate the lookout process. According to the rules, maintaining proper lookout requires that the ship 1) maintains 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) detects ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.

Navigating the ship is the task of the Officer in Charge of Navigation. In highly simplified terms, navigating the ship comprises of 1) checking with appropriate frequency that the course, position, and speed of the ship corresponds with the route plans, 2) fully appraising the situation and the risk of collision, stranding and other dangers to navigation, and 3) taking all immediate actions necessary to ensure the safety of the ship.

While the SCTW Chapter VIII rules are important in articulating what the shipborne humans must do when navigating the ship, they are not the only source of navigational regulation in MSSs. Second, for MSSs in international traffic, the SOLAS Convention

Chapter V together with other technical rules deal directly with navigational hardware. The rules regulate what *navigational equipment must be carried* and providing at times excruciatingly detailed requirements that technologies the crew uses in navigating the ship must meet. The STCW Code, third, establishes a detailed regulatory regime for *crew qualifications and training*. The STCW rules lay out what capability is required of MSS crew members and fundamentally affect the ship as navigational entity. One could say that these rules seek to regulate the character and capabilities of humans as cogs in sociotechnical navigational machines.

In MSSs, navigational regulation has three target surfaces through which gain traction. Regulations addresses how the humans were to work on ships while navigating it, what skills and competencies the humans were to have, and what technological aids they were to have at their disposal while working.

MSS navigation regulation works through affecting three regulatory target surfaces: workflows, navigational equipment, and crew skills.

4.3.1.3 The regulatory setting in MASSs

In MASSs, as the shipborne humans will wither away, the workflow and skills mediated regulatory traction surfaces will disappear, in whole or in part, leaving only the technologies to be targeted by regulators. Consequently, the currently multi-layered navigational regulation toolbox will become a monoculture, signifying a drastic change in regulatory patterns. MASS navigational regulation will have to target the ANS technologies. To do that, regulators will have to explore and find ways to affect ANS technology composition to ensure safe navigation.

> MASS navigational regulation will have to target the ANS technologies.

MASSs do not, of course, always rely entirely on technology for navigation. IN MO-CMASS, crews are present and navigate the ship. In RO-MASSs, humans are in present SCCs and take part in navigating the distance over a Distance. In both of the MASS types, some of the traditional regulatory instruments that target humans, correspondingly, can be used. These differences in ship character and affordances should, of course, be taken into account. Nevertheless, MASS navigational regulation will primarily be technology-mediated.

> MASS navigational regulation will have to primarily affect navigational technology.

In designing the future technology-oriented navigational regulation regime, one must, however, bear in mind that autonomous navigation systems comprise of multiple subsystems. The ANS subsystems have varying technological makeups and consist of qualitatively different hardware and software components, each with their individual regulatory challenges. SA systems, for example, are dominated by sensor equipment and signal processing and sensor fusion algorithms. Navigational planning, in turn, is nested inside navigational computers and utilizes an altogether different set of algorithms such as path search algorithms and external object models.

> MASS autonomous navigation systems consist of multiple subsystems with widely divergent technology compositions. Regulators should develop a framework that takes the technological heterogeneity into account.

In addition, MASSs will likely over time employ varying combinations of autonomous navigation technologies. For example, a CMASS may rely on its autonomous navigation system while sailing on high seas and use the system in a complementary to support crew decision-making in more congested waterways. A UCMASS may, on the other hand, be entirely reliant on its autonomous navigation system whenever it operates autonomously, but only use the SA system components when operated by SCC staff.

> The different levels of human involvement will further complicate regulatory design.

Consequently, in keeping with the technical exposition in Chapter 2.1 above, this report approaches ANSs as containing three distinct processes that are treated as separate targets of regulatory efforts.

> These processes are voyage planning, situational awareness generation, and navigational planning.

However, here a note of the relative importance and character of the processes is in order. Of the three processes situational awareness generation and navigational planning are the primary regulatory targets. Situational awareness generation relies on sensors and a variety of algorithms to replace the MSS socio-technical lookout process. The SA generation process is crucial to MASS safety as it has direct and immediate safety implications. As SA systems contain multiple algorithmic components, the systems also offer unprecedented regulatory challenges.

The same is true of MASS navigational planning. Voyage planning, in turn, is a high-level, slow process in MASSs and has few, if any immediate safety implications. Barring environmental and climate concerns, there is little public interest in regulating the voyage planning processes. As a result, regulators should not treat the voyage planning process as a priority regulatory target in MASSs, but note that voyage planning regulation will contribute to CO2 emissions mitigation.

> Situational awareness generation and navigational planning have direct and immediate safety implications and should be the primary regulatory targets. Regulating voyage planning is important for environmental reasons while voyage planning is relevant due to its impact CO2 emissions

4.3.1.4 Structure of the discussion

In the following, the report will, first, discuss how autonomous navigation systems can and should be regulated. Most of the discussion will centre around what approval requirements should be established for situational awareness and navigational planning systems. The report will also briefly consider manning-related questions where necessary.

4.3.2 Charting the regulatory options

4.3.2.1 The options

As outlined above, MASS navigational regulation will have to target technological systems. Consequently, three possible regulatory options emerge.

Regulators could

1) impose technical standards mandating shipowners to use particular technologies in autonomous navigation systems (technological standards),
2) impose minimum standards for autonomous navigation system performance,
3) require that the autonomous navigation system algorithms be transparent, or
4) use a combination the three approaches.

4.3.2.2 Prescriptive technology regulation

The first option would entail that regulators 1) identify what technological approach can be used in ANSs and 2) use their expertise to specify what technological approaches should be used in autonomous navigation systems. Compliance with technology requirement is a condition for regulatory approval. (On different types of regulation see e.g. Ogus 2004; Baldwin, Cave, and Lodge 2010, Chapters 7 and 8).

This prescriptive command-and-control technology regulation approach requires that shipowners use specific technologies. It leaves the regulated little leeway to innovate and explore alternative technological solutions. The approach is common in the maritime contexts and, for example, dominant in much of SOLAS. SOLAS rules often establish exhausting detailed technical standards for ship construction and equipment to be used on ships. The SOLAS Chapter II-2 Part D 7.3.1, for example, regulates the strength of handrails in the following fashion:

> *"Handrails or other handholds shall be provided in corridors along the entire escape route so that a firm handhold is available at every step of the way, where possible, to the assembly stations and embarkation stations. Such handrails shall be provided on both sides of longitudinal corridors more than 1.8 m in width and transverse corridors more than 1 m in width. Particular attention shall be paid to the need to be able to cross lobbies, atriums and other large open spaces along escape routes. Handrails and other handholds shall be of such strength as to withstand a distributed horizontal load of 750 N/m applied in the direction of the centre of the corridor or space, and a distributed vertical load of 750 N/m applied in the downward direction. The two loads need not be applied simultaneously."*

Here, the landscape is, however, complicated. For example, SOLAS Chapter V Regulation 19 rules, at times, establish what like a very high-level rules devoid of details for navigational equipment. The high-level rules are, however, augmented by a host of Recommendations that then add detail to the high-level SOLAS requirements.

Prescriptive technology regulation will likely be used in regulating ANSs.

4.3.2.3 Performance-based regulation

Performance-based regulation offers a different approach to regulating autonomous navigation systems. Here, the regulators refrain from imposing demands on the specific technological composition of MASS autonomous navigation systems. Instead, they will articulate performance standards that the systems must achieve, regardless of what technologies manufacturers use. Consequently, the autonomous navigation systems are only certified for use if the certificate applicants can demonstrate that the systems meet the performance standards.

The IMO Polar Code is often hailed as an example of future maritime regulation. The performance-based rules in the Polar Code uses words somewhat more sparingly than the SOLAS rule cited above. Instead of dealing with handrails separately, the Polar Code establishes a general high-level "functional requirement":

> *"All life-saving appliances and associated equipment shall provide safe evacuation and be functional under the possible adverse environmental conditions during the maximum expected time of rescue" (8.2.2)."*

Now, multiple options exist for articulating the required level of performance. For MASS autonomous navigation systems, the performance standard could be set, first, to match human performance in generating situational awareness (human performance equivalent). Second, the minimum performance standard could be set by requiring that the certification applicant to demonstrate that the ANS has a proven real world track record of safety (*real world testing*). Third, the regulators could introduce a simulation-based approach to setting minimum performance standards and require that the ANS meet a minimum level of performance in *simulation testing* (See e.g. Baldwin, Cave, and Lodge 2010; Coglianese, Nash, and Olmstead 2003; Coglianese and Nash 2017).

> Performance-based regulation will be a feasible regulatory approach in autonomous ship contexts.

4.3.2.4 Transparency as a regulatory option

Transparency requirements could also constitute a regulatory option as ANSs contain multiple algorithmic components. The benefits of transparency approaches seem, however, limited in ANS contexts. On the one hand, many algorithmic components such as sensor fusion and path search algorithms may be fairly standardized and, thus, irrelevant in the transparency frame, while the interesting algorithmic components, such as signal processing and semantic mapping neural networks, will be key trade secrets for industry actors and mostly unexplainable. Requiring ex ante transparency and explainability could, thus, discourage investments in algorithm development, while accruing no safety benefits.

> Transparency regulation is unlikely to be effective in ensuring adequate SA generation on MASSs.

4.3.3 Regulating SA systems

4.3.3.1 Scoping the regulatory options

In the next two sections, the report will discuss how prescriptive technology regulation and performance-based regulation could be used to control the MASS situational awareness generation and navigational planning processes. The report will, in the following, outline a regulatory vision for regulating autonomous navigation systems. The discussion commences by scoping the regulatory for regulating SA systems.

Maintaining proper lookout is crucial to safe navigation. The Officer in Charge of Navigation on an MSS must know, for example, know what objects exist in the ship’s immediate environment, be aware of the meteorological, hydrological, and traffic conditions, and know the ship’s position. The same applies to MASSs. Consequently, IMO should draft and publish rules that require all MASSs to generate adequate situational awareness to ensure safe navigation.

> IMO should draft and publish rules that require all MASSs to generate adequate situational awareness to ensure safe navigation, using t

Based on the discussion above, regulators have two feasible building blocks when designing the regulatory regime for MASS SA systems. The regulators can resort to prescriptive technology regulation and performance-based regulation. In the following, the report will discuss both options in detail, but it will start with addressing whether different MASS types should be allowed to use SA systems operating at various capability levels (the stratified approach).

4.3.3.2 Stratified standards

Some industry actors have advocated that a stratified regulatory approach to SA system approvals should be adopted (Lehtovaara and Tervo 2019). In this approach, regulators would allow SA systems with varying capabilities. In practice, this would entail that low-performing SA systems would be allowed on MASSs operating in low risk operational domains, while autonomous or remote operation in high risk operational design domains would require the use of a high-performing SA system.

Here, regulators should take into account two considerations. First, UCMASS navigational capabilities are always conditioned by the SA systems. In AO-UCMASSs, the navigational planning is entirely dependent on the situational awareness generated by the SA system. In RO-UCMASSs, the SCCs may provide some complementary SA generation capability, but the capability is severely constrained: SCC staff may be able to analyse the data the ship transmits onshore, and, possibly, second guess the technology-based situational awareness. Were a UCMASS equipped with a low-performing SA system ever to enter a high-risk operational domain, there would be a considerable risk that the UCMASS would not be able to navigate the domain safely, even with support from a SCC. Consequently, while some risks could be mitigated by enhancing connectivity reliability and devising effective minimum risk fall-back navigational strategies, UCMASSs should always be equipped with high-performing SA systems, unless operating in exceptionally low-risk operational domains.

> Regulators should exercise extreme caution when approving unsophisticated SA systems for use on UCMASSs.

Second, the crew provides AO and RO-CMASSs a backup human sensory capability. Thus, an SA handicap caused by a low-performing SA system can be eliminated when the crew is activated. This suggests that low-performing SA systems could be allowed for use on CMASSs in low risk operational domains. Two further issues should, however, be considered. First, crew activation takes time. If low-performing SA is allowed, a temporal safety envelope of, for example, 20 minutes should be established in order to allow the crew to be activated before the ship enters a high-risk operational domain. Second, crews tire. Thus, a ship using low-performing SA system should be adequately manned to ensure that the crew can operate it safely during the time the ship is in a high-risk operational domain.

> In CMASSs, a safety envelope should be imposed for ships with unsophisticated SA systems.

Consequently, IMO should be cautious when exploring under what conditions low-performing SA systems should be allowed to be used on CMASSs. The use of such a SA system should only be allowed if the system can maintain an adequate situational awareness in a low risk operational design domain and the ship can restore manned outlook before entering a high risk operational domain. The ship should also be adequately manned to allow safe manned operations during the time the ship can be expected to remain in a high-risk operational domain. Low-performing SA systems should likely never be used on UCMASSs.

4.3.3.3 Technological standards for situational awareness systems

In prescriptive technology regulation, regulators mandate the use of specific technologies. In SA systems, adopting this approach would entail that regulators specify which types of sensors, software, and algorithms must be used in SA systems. Prescriptive technology regulation may be useful in relation to sensors, but will likely fail in relation to software.

4.3.3.3.1Sensor rules

As recounted above in Chapter 2, generating a situational awareness requires that MASSs run a large number of sensors. The sensors include various radars, lidars, visible light cameras, infrared cameras, ego ship health sensors, and environmental condition sensors. Crucially, no industry standard instrumentation packages have yet emerged, and no technical standards have been promulgated on SA systems as a whole.

> Rules on marine sensors should be reviewed.

The need for new technical standards for sensors is highly uneven. Many equipment types, such as marine radars, tracking and plotting aids, AIS devices, GPS receivers, and Electronic Chart Display and information Systems, have already reached a mature technical state. For this kind of equipment, the current technical regulations will likely be sufficient in MASS contexts as well. MASS deployments will, however, also introduce novel types of sensory equipment, such as cameras and lidars not used on ships previously. For visible light cameras and lidars, in particular, new rules will be needed.

> Mature sensors will likely require no new regulation, but cameras and lidars will need technology standards.

Cameras also pose another standard-setting challenge. As primary semantic information sources on MASSs, cameras will replace the complex, multidimensional, and highly important sensory capability that humans have provided on manned ships. SA system object detection and classification capability is to a large extent a function of the capability of the SA system's visible light cameras.

> Cameras are important regulatory targets as they provide the ships with semantic information.

Cameras, consequently, determine the ship's action capabilities: if the ship cannot detect an object, it cannot evade it or plan any other action in relation to it. Decisions relating to cameras and array design will, consequently, involve fundamental ethical and practical choices that have important upstream implications. This fact underscores the need for binding technological regulation of camera setups. If the regulators articulate minimum operational ontologies, the camera rules should be aligned to match these ontology specifications.

> Camera regulation should be aligned with operational ontology rules.

4.3.3.3.2 Software rules

In addition to countless sensors, SA systems contain software components and algorithms. While prescriptive technology standards may be effective in regulating the SA system hardware, the approach will likely fail to ensure adequate software performance, as the space of possible algorithmic and code designs is more expansive than for physical designs. Nevertheless, prescriptive technology regulation may play a role, and regulators should require that certification applicants demonstrate that SA systems use robust methodologies for both spatial and semantic signal processing as well as sensor fusion. However, as likely implementations will differ for at least semantic signal processing, detailed prescriptive software regulation will probably be counterproductive.

> Detailed prescriptive software regulation will likely be counterproductive.

4.3.3.3.3 Sensor redundancy

Ensuring adequate sensor redundancy for safety-critical sensors is a regulatory priority, for which IMO should adopt a layered strategy. First, it is imperative to closely study the autonomy sensor packages as they emerge. Second, IMO should also carefully study whether existing regulations are sufficient to govern mature technologies on MASSs. For new technologies that have not been previously used on ships, IMO should articulate minimum technical standards. Visible light camera regulation is particularly imperative. Importantly, regulators should also analyse what redundancy requirements should be imposed.

> Ensuring adequate sensor redundancy for safety-critical sensors is a regulatory priority.

4.3.3.4 Performance standards

Performance standards are the other option available for regulating MASS SA systems. Here, multiple alternatives exist.

4.3.3.4.1 Human equivalent performance

One option is to establish a human equivalent standard and require that the manufacturers demonstrate that the SA systems generate a situational awareness comparable to what a human crew would generate. While an intuitively attractive option at a first glance, the human equivalent approach may have its drawbacks. Requiring a human equivalent performance level misses the fact that humans and SA technologies have different strengths and weaknesses. SA technologies perform tirelessly but may lack the adaptability that humans have. Simultaneously, defining at what level humans perform may in itself prove elusive, as there might not be any useful metric for assessing how crews perform.

> Setting human equivalent performance standards will likely be counterproductive.

4.3.3.4.2 Real world testing

IMO could also draft a rule that requires certification applicants to demonstrate that the proposed autonomous navigation system has undergone real world testing and accumulated a sufficient track record of documented safe real-world operation. In detail, the standard could encompass the requirement that the autonomous navigation system has encountered and correctly processed

1) a sufficient number of normal and edge case traffic scenarios
2) in sufficient number of different weather and other external conditions
3) with no excessive failure events.

Track record accumulation could take place inside test areas using enacted traffic scenarios that probe both the everyday scenarios and the challenging edge cases with the systems navigating the ship under crew supervision. Alternatively, testing could take place in normal traffic, either online or offline (Peng 2020, 2019; Zhao and Peng 2017). Testing performance in challenging external conditions and traffic scenarios will, however, likely be slow, resource-intensive, and even risky.

> Real world testing for performance in challenging external conditions and traffic scenarios will likely be slow, resource-intensive, and even risky.

It would also likely require considerable investments in either manual or automated scenario analysis and documentation. While offline real-world testing could streamline the process, assuring adequate scenario coverage may remain a challenge. Similarly, specifying what can be considered a suitable selection of traffic scenarios will require considerable expertise in both maritime operations and situational awareness technology.

> Ensuring adequate scenario coverage will be challenging.

Consequently, real-world testing is probably not suitable to function as the sole performance standard. The approach, nevertheless, will likely constitute a necessary and useful safety verification layer when combined with simulation testing. Real world performance track records will be useful in validating that models used in simulation-based approaches are feasible. As with simulation testing, regulators should carefully consider how scenario specification is organized and managed, and what level of performance is acceptable.

> Real world testing is unlikely to be sufficient to ensure MASS safety.

4.3.3.5 Simulation testing

a) Introduction

The report has previously argued that technical standards, human equivalent performance requirements, and real-world testing may be insufficient instruments to ensure adequate safety of MASS operations.

The missing piece is found simulation testing, where SA systems are tested by simulating their performance using data from a large battery of scenarios in a virtual environment. The report argues that the simulation testing approach is likely best suited to provide the backbone for safety verification of SA system software components.

> Simulation testing will likely be the key method for ascertaining sufficient MASS safety.

The report will, in the following, discuss five aspects of simulation testing that emerge as crucial. First, as algorithms in the different parts of the SA system differ, appropriate methodologies must be developed to address the unique concerns in each algorithm type. In addition, the interaction of the different algorithms has to be tested as well. Second, effective simulation testing requires that the simulation scenarios cover a sufficiently large and representative set of common and edge case scenarios that MASS may encounter. Third, enough tests must be run to get a good statistical understanding of the system's performance capabilities. Fourth, regulators must set a reasonable standard for acceptable performance. Fifth and finally, the tests have to be developed and administered by an appropriate body. The report will discuss each issue separately.

b) Algorithmic variety and testing

Spatial and semantic signal processing and sensor fusion processes differ from each other in terms of the algorithms employed in the processes. Object detection, classification, and semantic segmentation approaches build primarily on a variety of computer vision technologies. Sensor fusion algorithms, instead, take the pre-processed spatial information and object label feeds from a variety of sources, such as radars, lidars, maps and charts, AIS, and cameras, and combines them to generate a unitary object map. The algorithms are commonly rule-based.

It seems conceivable that object detection, classification, and semantic segmentation subsystems of MASS SA systems could be verified separately from the rest of the SA system using uniform sets of visual data for each trading area. Likewise, it seems conceivable that standard sets of visual data could be used across manufacturers and platforms, as the basic technological features of camera data are largely uniform. Consequently, what data sets are used in testing and what standard is set for adequate accuracy, are, likely, crucial questions.

> Semantic algorithms could possibly be verified using standard data sets across manufacturers.

Sensor fusion algorithms may pose a more difficult challenge, with two problems likely to emerge. First, simulating entire object spaces may be difficult. To gauge how the sensor fusion algorithms perform, the data instances must constitute dynamic object spaces, i.e. environments that change over time. Building the scenarios will likely prove more resource-intensive than collecting representative visual data sets for semantic signal processing tests. Second, building the tests may also prove problematic if sensor performance, data types, and data representation methods vary across manufacturers. If this is true, the only way to produce the data feeds for the sensor fusion process is to model the sensors. To our knowledge, the industry is still working on developing the required technologies. If the sensor modelling challenges are overcome, testing efficacy depends on what is included in the representative samples of dynamic object spaces, and what standards are set for adequate accuracy.

> Verifying sensor fusion algorithms may prove challenging.

c) Test scenarios

Test scenario data sets constitute the second crucial issue in simulation testing. Building the test scenarios will require considerable investments and expertise. The test datasets should explore multiple dimensions of system performance, and contain scenarios that intentionally probe system weaknesses and the hard edge cases where the systems' operational envelopes are pushed. As the EU AI guidelines provide, "adversarial testing by trusted and diverse 'red teams' deliberately attempting to 'break' the system to find vulnerabilities" should be included.

> Test scenarios should include scenarios that explore edge cases.

d) Simulation volumes

Simulations should be performed in sufficient quantity to allow for statistical probing of system performance. Catching system vulnerabilities may require thousands of simulation-runs under various scenarios.

e) Standard for accuracy

The fourth crucial question pertains to the required performance standard. Conceptually, setting performance standards could be relatively straight-forward. Once the scenario set is finalized, regulators need to articulate what success rate the systems must meet. However, a single performance metric will likely be insufficient. As the EU guidelines for ethical AI state "multiple metrics should be developed to cover the categories that are being tested for different perspectives".

> Multiple metrics should be used to gauge SA system accuracy.

Regulators should likely set the performance standards based on a risk analysis, taking into account the frequency of failure, post-failure control capabilities, and the severity of the consequences of failure. Here, standard setting is bound to be demanding. First, the testing institutions will have to grapple with the variety that failure types will inevitably exhibit. Some failures will be frequent but either easily controllable or insignificant in their consequences. Others may be infrequent but catastrophic in their consequences. The performance standards should reflect this.

f) Managing the testing platform

If the aforementioned problems are solved, a crucial question remains: who should develop and administer the tests? As recounted above, developing appropriate image or scenario sets will require considerable expertise in both seafaring and autonomy technology. Seafaring expertise is needed to identify the scenarios the ships are likely to encounter. Autonomy technology expertise, in turn, will be required to develop scenarios that explore how the systems perform in the hard edge cases that push the systems' capabilities.

> Developing a testing platform requires considerable investments and expertise.

Although manufacturers will likely test the sensor systems during the design phase, self-regulation approaches to testing should not be adopted. There is ample evidence from both the Volkswagen diesel scandal (Coglianese and Nash 2017) and the LED TV energy debacles to suggest that self-administered or knowable tests may invite gaming attempts. As seafaring is a high-risk activity, the potential for significant third-party damage is high, and mitigation efforts are likely ineffective, MASSs should be subject to a rigorous, hard-to-game verification regime. The report, consequently, recommends that an independent third party, or parties, develop and manage the test datasets and administer the tests. The datasets should not be available for use as training data.

> Regulators should not adopt a self-regulatory approach to testing.

The recommended approach has its drawbacks. It will require considerable investments by regulators or their designates, as building and managing the scenario sets will be expensive. The cost issue will likely be compounded by the need to test and verify all software versions prior to approval and deployment. However, the shipping community has a long track record of being subject to third party inspections and classification societies have already indicated their interest in developing capabilities for inspecting and verifying MASS seaworthiness.

SA system regulatory targets and options are summarized in Table 8.

Table 8. **SA system regulatory targets and options.**

SA system component	Prescriptive technology regulation	Real world testing	Simulation testing
Sensors	Primary method. Regulate sensor setups, capabilities.	Primary method. Verify performance offline in various conditions.	May be needed for verifying composite SA system performance.
Semantic signal processing	Complementary. Requirement that robust methodologies be used.	Limited utility. Slow and expensive to implement.	Primary method. Verify performance using standard image data sets.
Signal processing	Complementary. Requirement that robust methodologies be used.	Primary method. Verify performance offline in various conditions.	Limited utility.
Sensor fusion	Complementary role. Requirement that robust methodologies be used.	Complementary. Limited utility. Slow and expensive to implement.	Primary method. Verify performance using scenario data. May require sensor modelling.
Situational awareness system as a whole	Limited utility as technological compositions are likely to vary.	Complementary. Acceptable performance to be required.	Primary method. Acceptable performance to be required.

4.3.4 Regulating navigational planning systems

4.3.4.1 Scoping the regulatory options

Navigational planning is the second crucial process running in MASS autonomous navigation systems. Navigational planning takes place on two levels. Voyage planning is the strategic planning process that allows the MASS to create a high-level plan for travelling from its port of departure to its port of destination under expected conditions. Local path planning, often also known as collision avoidance, is a tactical process where the MASS adapts its high-level plans to environmental changes while implementing the global voyage plan.

The voyage planning process is not an interesting regulatory target apart from environmental concerns. The report recommends that the regulators should focus on regulating the local path planning process.

> Voyage planning is a secondary regulatory target.

Local path planning is a difficult computational problem. Most applications implement a layered design that combines complex algorithmic path search strategies with rule-based secondary algorithms and dynamic models for both objects in the external environment and the ego ship. The path search algorithms provide its ship the capability to find feasible paths. The rule-based secondary algorithms constrain the search space, ensure that the ship's movements are foreseeable, and make sure the ship complies with the COLREGs rules. The external environment object models allow the ship to predict the movement of other ships. Ego vessel models contribute to the process by allowing the ship to predict its own movements after actuation commands are given. In the following, the report will discuss three main sets of issues encountered in navigational planning systems. First, the report will discuss whether stratified navigational planning requirement should be allowed for different types of MASSs. Second, the report will Identify the regulatory focal points for navigational planning systems. Third, the report will discuss what principles should guide simulation testing for navigational planning systems.

> Local path planning is a complicated but important regulatory target.

4.3.4.2 Stratified standards

As with the SA systems, one might argue that stratified regulatory approach should be adopted for navigational planning systems on different kinds of MASSs. A CMASS could be, for example, allowed to operate in low-risk operational designs even if its navigational planning systems would not survive in complicated traffic scenarios in congested waterways. The argument builds on the idea that local crews and SCCs can provide backup navigational capabilities and, thus, decrease the risks associated with autonomous navigation systems.

Here, a clear demarcation line runs in a familiar place, between CMASSs and UCMASSs. CMASS crews provide a genuine and reliable backup navigational capability. The crews can be trusted to reliably take over navigational tasks if and when activated. SCC staff navigational capability, however, is always dependent on connectivity, as it requires communication. Regulators should never approve UCMASSs without demonstrated capability of safe navigational planning in all operational domains that the ship may encounter.

> UCMASS should never be allowed to trade without demonstrated capability of safe navigational planning.

In CMASSs, operating with navigational planning software that has shortcomings might not create unacceptable risks if a sufficient safety envelope is enforced, and if the crew can take over navigation before the ship enters a high-risk operational domain. Consequently, IMO may have reason to explore whether CMASSs could be certified to trade in an operational design domain if the navigational planning systems have a demonstrated capability of safe navigational planning within the operational design domain. The regulators should ensure that the transitions between operational domains are slow enough to allow the local crew to be activated before the ship enters high-risk domain. The rules should also ensure that the ship is adequately manned even for extended periods of manned operations.

Regulators should explore whether CMASS could be allowed to trade with unsophisticated navigational planning systems.

4.3.4.3 Prescriptive technology regulation in navigational planning

Navigational planning is a software dominated process. Prescriptive technology is consequently unlikely to play a useful role.

4.3.4.4 Focal points for regulation

4.3.4.4.1 Search algorithms

Within the local path planning process, three regulation-relevant algorithm design issues will likely arise. The first issue is related to the search algorithms. Academic literature suggests that potential field approaches will likely be prevalent in local path planning systems. In potential field approaches, path planning is approached as an optimization process. Each target object to be avoided is allocated a repulsive "cost", while areas that the ship is permitted to enter receive an attractor, a "negative cost". Path planning, then, is a search for the lowest possible cost path (Campbell, Naeem, and Irwin 2012; Polvara et al. 2018; for specific algorithmic approaches, see e.g. Lyu and Yin 2019; Lazarowska 2018).

Search algorithm design involves important ethical choices.

Defining the value of the attractive and repulsive forces involves significant ethical decisions, and is likely to dictate what path the ship takes up (Pan, Thornton, and Gerdes 2016) and constitute the venue where many of the MASS "trolley problems" will be resolved. Consequently, cost allocations should be a regulatory focus for potential field approach-based path planning systems.

Cost allocations involve significant ethical choices. Therefore, if the systems use search algorithms with cost functions, the report recommends that certification applicants should be required to describe in detail how object costs were arrived at and justify and document the main design choices underlying both the search algorithms and cost allocations. The documentation should be available to authorities.

Applicants should be required to describe and justify search algorithm designs.

4.3.4.4.2 COLREGS compliance

Second, MASSs will have to comply with the COLREGs rules, as the vessels will trade in mixed traffic environments for the foreseeable future. The only feasible way to coordinate traffic is that all participants engage under a single ruleset. Consequently, ensuring that MASS navigational systems will make COLREGs compliant decisions should be a regulatory priority.

MASS should comply with standard COLREGS rules.

Some commentators have argued that incorporating COLREGs rules into the path planning engines will be technically challenging, as the rules are designed for human operators, not computers. Importantly, COLREGs contain notions and standards that cannot be translated into machine-readable, quantified format. For example, the rules often refer to open-ended and vague reference points, such as the "ordinary practice of seamen" (COLREGs Rule 5) and "safe speed" (COLREGs Rule 6 and 19) (Porathe 2019). Other commentators have, however, argued that COLREGs can be integrated into MASS navigational systems' decision-making (Zhou et al. 2020; Naeem, Henrique, and Hu 2016; Zhao and Roh 2019).

Here, difficult regulatory and ethical challenges will likely emerge. The first challenge concerns the appropriate MASS "risk appetite". COLREGs Section II rules, on the one hand, give vessels a right to not be impeded by others. However, the vessel with the right to proceed unimpeded is under COLREGs Rule 8(f)(iii) not exempt from the duty to take necessary action to avoid collisions, if the vessels "are approaching one another so as to involve risk of collision." Consequently, the key parameter of a MASS path planning system is its level of aggressiveness: how stringently does the MASS cling on to its right of way? IMO should consider issuing a MASS design philosophy document that would set guidelines for appropriate MASS risk appetites.

MASS risk appetites should be subject to regulation.

4.3.4.4.3 External object models

The search algorithms work well in static environments where the ego ship is the only moving object. Surviving the real world, however, requires that the ship can manage scenarios where objects in her vicinity are dynamic and move, at times even erratically. Effective local path planning, second, requires building models that can predict how the other objects move. Here, model design choices will significantly affect how the MASS will "assume" other objects will move and, consequently, impact the ship's navigational planning outcomes. As what other ships will do will be of crucial significance to the ego ship's reactions, external object models should constitute an important regulatory target.

External object models should face regulatory scrutiny.

The assumptions underlying models are crucial to model design. The models range from simple current movement trajectory extrapolation and COLREGs compliant trajectory prediction to sophisticated machine-learning based models that use historic AIS data to determine how the target object will behave based on the observed past behaviour of similar objects.

The report recommends that certification applicants should be required to demonstrate that navigational planning systems can adequately model external object behaviour in the ship's operational design domain. As external object models involve ethical trade-offs, the applicant should be required to describe the models, and document and justify main design choices to certification authorities.

> External object model design choices should be described and justified.

4.3.4.4.4 Real world and simulation-based performance standards

As with SA generation, adequate navigational performance can likely not be ensured by technical regulation or transparency requirements alone. Instead, regulators should require that certification applicants demonstrate navigational adequacy, first, by submitting an acceptable real-world track record of supervised performance, and, second, by passing simulation testing.

> Real world testing and simulation testing should constitute the backbone of path planning system regulation.

As with SA capability testing, the devil lies in the details of the testing setups. The problems are largely identical to those encountered in testing SA technologies. Regulators will have to, first, ensure that the tests include appropriate scenario sets, which explore navigational performance in scenarios relevant to the MASS operational design domain. Second, threshold conditions for acceptable test performance must be set.

> Testing will likely be marred by same problems as SA system testing.

For simulation testing, the process is complicated by two factors. First, SA systems condition how MASS navigational systems perform their navigational tasks. Consequently, while testing algorithmic performance by using the standard "ready-made environmental maps" could be fast and cost-effective, and, thus, an attractive option, the approach might create a distorted picture of actual MASS navigational performance. Accounting for SA system idiosyncrasies would likely require simulating sensor performance and running the simulations on such sensor data that the MASSs would likely have access to if they encountered the scenario in real life. This will be a significant factor in increasing testing costs.

SA system idiosyncrasies may complicate simulation testing.

Second, ship features, such as its size, hull hydrodynamics, power output, and propulsion system capabilities in different weather conditions, affect what navigational choices are available. Consequently, testing platforms will have to be able to adequately model ego ship handling and the manoeuvrability constraints that flow from ship designs.

Regulatory targets and options for navigational planning systems are summarized below.

Table 9. Regulatory targets and options in autonomous navigation planning systems.

Navigational process	Prescriptive technology regulation	Real world testing	Simulation testing
Global path planning	Limited utility. Regulation necessary mainly for environmental reasons.	Limited utility. Regulation necessary mainly for environmental reasons.	Limited utility. Regulation necessary mainly for environmental reasons.
Search algorithms	Complementary. Requirement that robust methodologies used and appropriate risk appetite implemented.	Limited utility. Slow and expensive to implement.	Primary method. Verify performance using scenario data sets.
Ego ship models	Complementary. Requirement that robust methodologies be used.	Limited utility. Slow and expensive to implement.	Primary method. Verify performance in simulations.
External object models	Complementary role. Requirement that robust methodologies be used.	Complementary. Limited utility. Slow and expensive to implement.	Primary method. Verify performance using scenario data.
Navigational planning systems as a whole	Limited utility as technological compositions are likely to vary.	Complementary. Acceptable performance to be required.	Primary method. Acceptable performance to be required.

4.3.5 Regulating autonomous navigation systems holistically

To sum up, ensuring adequate MASS navigational safety will require that the SA and navigational planning components are subjected to rigorous regulation that incorporates both prescriptive technological and performance standards.

Verifying ANS safety holistically will require that the ships are subjected to both real world testing and simulation-based testing

4.3.6 Human-ANS interaction

4.3.6.1 Humans and ANSs

Despite navigation transforming into an increasingly technology-dominated process, humans will retain an active role in navigational processes. On CMASSs, local human crews will periodically navigate or, at least, supervise the ship. Humans in SCCs will contribute as well. The remnants of human raise three sets of questions: humans as ANS backups, the effect ANSs may have in enhancing crew capabilities, and the complications ANSs will offer for devising accountability mechanisms

4.3.6.2 Humans as ANS backups

Humans provide backup capabilities that complement both the ships' technological SA and navigational decision-making capabilities. Regulators will have to decide whether and to what extent the backup human capabilities can be appealed to, in order to offset shortcomings in the ships' navigational capabilities.

Similarly, industry actors have envisaged that a single SCC operator could operate multiple vessels simultaneously. The report recommends that prior to approving such practice, regulators must conduct studies over the cognitive loads that operating a MASS imposes on SCC staff under various conditions. After the studies are completed, the regulators must set binding requirements on SCC staff levels for various operational circumstances, and outline what escalation procedures should be in place to ensure adequate SCC staffing levels if and when conditions on ships change.

> Regulators should exercise caution when determining required SCC staffing levels.

Insurance policies may constitute a further complicating factor. Most insurance statutes and policies allow the insurer to refuse payment if the accident was caused by the actions of the non-seafaring assured or their management. The geographical distance between the assured and the master and the crew helps enforce the independence of onboard navigational decision-making in MSSs. In MASSs, ensuring insurance provision may require that a "SCC master" is appointed for all MASSs. The master, then, would retain the master's current status as a sovereign over the ship during its voyage and have the responsibility for maintaining adequate situational awareness and the exclusive right to make navigational decisions.

4.3.6.3 ANS as crew capability enhancement

Second, MASS technologies will offer unprecedented navigational assistance to CMASS human crews. The crews will have information currently not available for MSS crews and can rely on MASS technologies to perform some of the lookout work currently performed by humans. Similarly, navigational planning systems may help crews by monitoring the ship and offering ready-made route plans, possibly allowing the crew to merely oversee the ship. The lookout and navigational assistance will likely trigger calls for reduced manning.

IMO should study what effects MASS technologies will have on the crew's work and cognitive loads, and issue guidelines for evaluating what manning reductions, if any, should be allowed. Flag states should, then, issue appropriate safe manning certificates.

> Regulators should exercise caution when assessing whether manning requirements be reduced.

4.3.6.4 Accountability for navigation on MASSs

While current MSS rules establish clear lines of accountability for navigational outcomes, the lack of humans on MASSs will muddy the waters.

The existing rules establish a two-pronged allocation of duties. On the one hand, FMC 6:9 requires that the master "ensure that the ship is navigated and handled in accordance with the ordinary practice of seamen". On the other hand, the criminalization in FMC 20:2 makes "masters, chief engineers and others person performing assignments that are of substantial significance to maritime safety" punishable by a year's imprisonment or a fine if they neglect to do what an ordinary seaman would have done to prevent a maritime accident. Consequently, all crew members who fail to do what an ordinary seaman would have done to prevent an accident are criminally liable.

On MASSs, the crucial question is how accountability for residual human navigation efforts should be arranged. The mode in which a MASS operates crucially affects who should be held accountable for accidents. For MO-MASSs, the situation is clear-cut. MO-MASSs are indistinguishable from MSSs and should be treated as MSSs. In AO-MASSs, humans are not directly involved in the navigational decision-making, neither on board nor in SCCs. No human is conducting lookout or making navigational decisions. Here, accountability should follow action capability: no one should be held personally accountable for an outcome they could not affect, and, conversely, only people who can affect outcomes should be held accountable.

> Accountability should follow action capability.

In AO-MASSs, the application of the principle indicates that primarily either shipowners or parties controlling ANS development processes should be held accountable for the accidents caused by AO-MASS ANS shortcomings. Shipowners and ANS developers would be accountable for their failure to ensure that the ANSs are capable of navigating the ship safely. For shipowners, the situation is comparable to their failures to ensure that an MSS is seaworthy. For ANS developers, accountability would have previously sounded in contract or product liability. Existing FMC and Penal Code criminalizations together with civil liability rules will likely be sufficient to ensure accountability.

> Shipowners and developers should be held accountable for AO-MASS navigational errors.

Hard edge cases may emerge when a human is *de facto* monitoring a ship that de jure is operating in the AO-MASS mode. Existing rules require that all seamen that have a possibility to take action to prevent an accident must do so. The rules also make the seamen accountable for failures to take appropriate action. An appropriate approach would seem to be that SCC staff and other involved parties (including seamen on board an AO-CMASSs) who are capable of taking action to prevent an accident must do so.

In RO-MASSs, the accountability landscape is complicated, as the MASS technologies affect the human lookout and navigational decision-making processes disparately. SCCs operate RO-MASSs, bearing the responsibility for navigational decision-making. SCC staff, consequently, has control over navigational outcomes. Thus, SCC staff should be accountable for accidents caused by their errors and omissions in navigational decision-making. The lookout failures, however, should be treated differently. Remember that in RO-MASSs, SCC staff's situational awareness is inevitably dependent on sensor technology performance and connectivity conditions, with SCCs providing a limited secondary sensory capability. Consequently, the SCC staff may have limited control over and capability to affect how comprehensive and up to date their situational awareness is. SCC staff should, however, be accountable for its lookout failures to the extent they were not caused by SA system shortcomings. Either the shipowner or the ANS developed should, in turn, be accountable for any failures that have root cause in ANS shortcomings. Implementing the approach may require changes to FMC rules.

> SCC staff should be held accountable for lookout and navigational errors they commit.

4.3.7 Conclusions

To summarise, the following conclusions can be drawn.

Regulatory standards ensuring that autonomous navigation systems (ANS) are capable of navigating the ships safely constitute the bedrock of the regulatory framework on which all MASS regulation will and must be built. The report outlines the regulatory landscape, sets out the various regulatory options, and discusses their strength and weakness.

Ultimately, the report arrives as a recommended structure for the future ANS regulatory framework.

1) The future autonomous navigation regulatory framework should be drafted by IMO and introduced as an amendment to SOLAS.
2) The framework should focus on ensuring adequate navigational capability to secure navigational safety.
3) The rules should target situational awareness and navigational planning systems separately, as the systems' technological compositions are different.
4) Regulators have three options available to address autonomous navigation systems problems: engage in prescriptive technology regulation dictating what technologies should be used; set performance based standards; or rely on transparency as a regulatory device.
5) Regulators should put in place an approach that combines performance-based rules and prescriptive technology regulation.
6) The performance-based rules should build on a hybrid simulation and real-world testing approach. The rules should mandate that an independent third party develops, maintains, and administers the simulation tests.

4.4 Other regulatory issues

Above, the report argues that the highest regulatory priority is that regulators develop a framework that ensures safe MASS navigation by drafting rules the MASS autonomous navigation systems.

In addition to this regulatory framework, several other interventions will be needed. The report will briefly discuss five additional regulatory flash points. Liability and accountability for MASSs and possible revisions to liability and accountability rules and data and infrastructure regulation needs will be discussed separately.

4.4.1 Regulating RO-MASS SCCs

The first regulatory flash point to be discussed here relates to how SCCs are organized. In RO-MASSs, SCCs replace both the crews as a navigational workforce and bridges as navigational workspaces. Consequently, the fact that RO-MASS safety is affected by the way SCCs function as navigational decision-making entities, as well as the way they are organized as physical spaces and technology assemblages consisting of various devices, has resulted in a clear interest in regulating them. The existing rules regulating the functions that SCCs will perform in RO-MASSs are contained in the SOLAS, COLREGs, and the STCW Conventions.

4.4.1.1 Regulating SCC "remote bridges"

The SOLAS rules deal primarily with how bridges are organized as physical spaces and technology assemblages. Thus, SOLAS should be updated to articulate the requirements for organising and equipping the SCC "remote bridges".

Remote bridges should be designed and equipped to maximise the SCC staff's capability to remotely navigate the ship safely. As data presentation is the key issue, the IMO rules and Guidelines on ECDIS equipment may provide a useful template for the "remote bridge" regulatory framework. The ECDIS rules (SOLAS Chapter V Regulation 19 and the concomitant MSC Guidance document (IMO 2017a) and IHO (2014) Standard) have emerged out of decades of research on human cognitive ergonomics. Various methods of presenting navigational information have been scientifically studied, and, then, display types and sign nomenclature have been optimized for maximum cognitive ergonomy. Consequently, it seems worthwhile to repeat the ECDIS process to specify what technology should be used on "remote bridges" and how situational awareness data should be presented.

The regulatory output should include technical standards for data presentation equipment and detailed guidelines and standards for what data should be displayed and how. As MASS data transfer rates will likely vary greatly, SCCs will have to operate under significantly variegated informational conditions. The regulations and data presentation methods should account for the differences in information availability and density. For example, the SCC staff should be able to know whether it operates using, for example, raw, unprocessed radar camera data or whether the data has been compressed to generic representations to enable low-bandwidth transmissions, and algorithmically recreated for display purposes in the SCC.

> Remote bridge designs should be regulated.

4.4.1.2 Regulating SCC staff

In addition to SCC technologies, the humans have to be regulated as well. Here, the regulatory framework has to cover two areas. First, the future regulatory framework should contain rules for "remote watchkeeping" similar to the watchkeeping rules currently contained in the STCW Convention and COLREGs. Second, the rules need to replicate, *mutatis mutandis*, the STCW training and qualification rules now applicable to MSS master and crews.

Remote watchkeeping rules will have to regulate the organization of navigational work in SCCs. Importantly, the rules will also have to articulate the framework for determining the minimum level of SCC staff required for operating a ship. Here, the industry will likely argue that a single operator should be allowed to operate multiple ships at a time, at least in low risk operational domains, if more resources can be allocated should the conditions change. The regulators should conduct studies on the cognitive workloads that operating or overseeing multiple ships create. The minimum staffing levels should be articulated based on the findings of these studies.

The training and qualification rules offer a unique set of challenges. The capabilities and skills required of SCC staff will likely differ significantly from those required of MSS crews. Drafting the rules on SCC training and qualifications will require comprehensive studies of the SCC working environment and the tasks the staff will perform.

> Rules on SCC staffing and qualifications will have to be articulated.

The framework should also regulate the interface between the possible local crews and the SCC staff, determining the lines of command and who bears the ultimate command authority on ships. Similarly, the framework should also regulate interactions and division of authority between SCC staff and the shipowner's management.

> Interface between SCC and shipowner representatives needs regulation.

4.4.2 Regulating connectivity

Connectivity is the second regulatory issue to be discussed here. MASSs will rely on various types of communication equipment to transmit data onshore and to the ship. Connectivity is needed for facilitating SCC operations, monitoring of autonomous operations, ego ship and cargo health, managing the ship as a commercial asset, and the scheduling of necessary maintenance work.

The report details the connectivity and bandwidth requirements above in Chapter 2. Understanding the bandwidth requirements of various data transmission tasks constitutes the starting point for building the future connectivity regulation framework. The future rules should work to ensure that ships, at a minimum, carry connectivity equipment that provides the ship with adequate connectivity to enable safe navigation. The regulators will likely wish to issue minimum technical standards for the connectivity equipment. Ensuring sufficient reliability should constitute an important aspect of the framework. Similarly, the regulations should include redundancy requirements.

> Regulations must ensure adequate connectivity and connectivity redundance.

Connectivity rules are intimately connected to marine infrastructure as connectivity will remain a challenge in high sea areas. To facilitate higher bandwidth communications outside the reach of cellular networks, regulators could mandate that MASSs carry equipment that allow them to function as cellular network base stations. If enough MASSs are in traffic simultaneously, the ships could, possibly, form a marine cellular network that at some end of the network reach a terrestrial base station. The network of shipborne base stations could, as a system, allow high bandwidth connections outside the reach of standard networks.

> Ensuring connectivity adequate infrastructure could mandate regulatory intervention.

4.4.3 Regulating fallback operational states

Connections will inevitably drop off, as all ships, including MASSs, experience blackouts, and can find themselves in environmental conditions they are not equipped or designed to handle.

The possibility that MASSs may experience technical failures that affect the ship's capability to navigate in their intended operational mode raises the question of how the ships should react to such failures. Some documents have suggested that the ship should initiate a "Dynamic Navigational Task Fallback" to counter navigational equipment and connectivity failures or entering an unauthorized operational domain. The fallback state is a navigational condition consisting "of different strategies, dependent on the operational condition "that are designed to take the ship to as safe a situation as is possible under the given circumstances. The "as safe a situation as is possible" is known as the "Minimal risk condition" (Rødseth and Nordahl 2017).

> MASSs should have navigational strategies to enable as safe as possible navigation even when navigational systems fail.

On CMASSs, the reactive pathways will be relatively straightforward. When the crews are not on active duty, any technical failure that affects the ships navigational capabilities should result in an alert. The crew should be activated and take over. Here, the time the crew takes to spin up to full action capability constitutes the regulatory challenge: should regulators intervene in the design processes and attempt to affect the ship's behavioural patterns? In CMASS, these transitory operational failure states are likely temporally relatively short and, thus, could be subject to light-touch regulation. Nevertheless, the regulators should articulate the design principles for such strategies and require that the approval applicants demonstrate that the ANS designs comply with the principles.

> In CMASSs, with human backups available, navigational failures are transitory, advocating for a light touch approach to fallback operational states.

On UCMASSs, the situation is more complicated. As the ships have no crew, humans cannot take over, at least not immediately. The ships will be on their own. The essential question is whether UCMASSs should be approved for use if they do not have adequate capability to navigate their operational design domains safely. The report has previously argued that approval should, in fact, be subject to applicants demonstrating adequate safe navigation capabilities within the operational design domains at all times. That leaves the regulators to grapple with unexpected transitions to operational domains that are more challenging than the operational design domains. Here, the DNT Fallback strategy is eminently sensible. If subjected to conditions that exceed their safe navigation capabilities, MASSs should have pre-programmed strategies that allow the ship to reach as safe a situation as possible. These might include reducing speed to the lowest level that still retains manoeuvrability, seeking out sheltered waterways or escaping congested waterways. In ships with dynamic positioning equipment or where anchoring is possible, stopping might be an option in benign hydrological conditions.

> In UCMASSs, designing effective fallback strategies is crucial as no human backups are immediately available.

4.4.4 Cyber security

The fourth regulatory flash point is cyber security. While it is an inherent aspect of autonomous navigation systems, the report discusses the issue separately.

Cyber security will be crucial to MASS safety. As connected entities, MASS navigational and other systems contain multiple attack vectors and surfaces, of which some have been identified below.

Crucially, MASSs will be unique entities as attack targets. The ships will likely be the largest physical robotic systems to be allowed to enter and operate in the open world. They will have a unique potential to inflict physical, irreparable harm to humans, the environment, and other property. Non-physical economic harms may also be extraordinarily large, as MASSs may become integral parts of the global value chain transport structures, and disruptions in transports may have repercussions that are felt across the system. While the MASSs potential to inflict other cyber harms (Agrafiotis et al. 2018), such as emotional, psychological, privacy, and social, may not be particularly pronounced, the physical and economic harm potential alone is significant enough to warrant heavy regulatory interventions.

> Cyber risk is a serious issue in MASSs.

IMO has already started its work on maritime cyber security. The work has resulted in a 2017 MSC FAL Guidelines document (IMO 2017b) that outlines a cyber risk management framework for MSSs. While the Framework provides shipowners a useful intellectual tool to start working on cyber related issues, MASSs will likely need far more heavy-handed regulation.

> At the minimum, cyber security should be included in the ISM Code as a regulatory target, and cyber security management should constitute as an integral part of all shipowner safety management systems.

In addition to explicitly mandating that all MASS owners institute, commit to, and engage in conscious and concerted cyber risk management, regulators should also explore mandating that approval applicants comply with to-be-issued prescriptive IMO technological standards, undertake constant red team security assessments, and have functional processes to address any vulnerabilities that may be discovered as conditions for MASS approval.

> Regulators should probably articulate prescriptive technology standards for cyber risk mitigation and require that shipowner take concerted measures to manage cyber risks.

Cyber risk insurance is also a concern. Currently, most hull and machinery policies exclude cyber risks from the scope of coverage. The standard London market language in LMA5402 is extensive and would, if incorporated into MASS hull policies, effectively exclude cover for any ANS failures. The clause reads:

> *"In no case shall this insurance cover any loss, damage, liability or expense directly or indirectly caused by, contributed to by or arising from: 1.1 the failure, error or malfunction of any computer, computer system, computer software programme, code, or process or any other electronic system, or 1.2 the use or operation, as a means for inflicting harm, of any computer, computer system, computer software programme, malicious code, computer virus or process or any other electronic system."*

P&I club rules do not typically include such language, but could do so. As cyber risks appear to be a significant concern in the MASS space, it might be advisable to update the EU Directive 2009/20/EC to mandate that P&I policies must cover cyber incidents. Otherwise, a huge hole might appear in P&I coverage.

> EU should update the Directive 2009/20/EC to mandate that mandatory P&I policies cover cyber risks.

4.4.5 MASS external communications

4.4.5.1 VTS and bridge-to-bridge communications

The fifth regulatory challenge relates to communications. Here, the regulatory interests stem from the fact that MASSs must be able to communicate with both authorities and other ships in order to facilitate safe and expeditious marine traffic.

Under existing rules, ships are required to communicate with a number of authorities. Vessel Traffic Service (VTS) operators constitute the most important authoritative communications partner. Communications with VTS operators (port authorities) are regulated, in Finland, by the Vessel Traffic Services Act. The Act implements the EU Vessel Traffic Monitoring and Information System Directive (2002/59/EC), and requires that all ships of more than 24 metres in length have to participate in the vessel traffic service by reporting to the VTS operator by using VHF channels. Notifying the VTS of the ship's presence is the master's task. Second, masters must also report all safety and pollution incidents their ship is involved in, as well as slicks, containers, or packages observed adrift on the sea. Third, masters are under FMC 6:12a obligated to report events and objects that cause an immediate danger to maritime safety, as well as deficient or misleading functioning, displacement, or disappearance of maritime safety implementations. The Act establishes other notification duties as well, including notices concerning arrival, departure, passengers, and cargo. These duties, however, can be performed also by someone other than onboard personnel.

While most VTS communications are unilateral, with the VTS operators as the recipient, communication may also, at times, be bilateral. VTS operators may issue orders requiring that ships must or must not use certain water areas, fairways or parts of fairways, anchor or to return to berth, or limit their speed in a water area or a fairway if the meteorological and hydrological conditions are exceptional or in case of special transports, search and rescue operations, or some other factor that restricts or endangers traffic in the VTS area. While masters always remain responsible for navigating and manoeuvring the ships, VTS providers may also offer assistance and advise to ships over VHF channels. Arranging pilotage also requires bilateral communication. Similarly, coordinating with other authorities requires that the ship has a capability to maintain a radio watch and receive natural language communications. Additionally, bridge-to-bridge communications are essential to traffic safety, and ships must maintain radio watch in order to ensure safe navigation.

> Regulators should develop a regulatory framework that ensures that MASSs are capable of communicating with VTS operators and other ships.

4.4.5.2 Communications in MASSs

In MASSs, some communication trouble is bound to emerge. In MASSs operated by local crews, existing rules will likely be sufficient and pose no challenges. If a CMASS, however, operates under SCC control or autonomously, challenges may arise. While SCC staff can probably take over the masters' and crews' communication and notification duties, and should also be required to do so, connectivity breakdowns and difficulties may mar their performance. While e.g. arrival and departure notifications can likely be made even under limited connectivity conditions, bridge-to-bridge communications and instant communications with VTS or pilots may be impossible. As the onboard crew may be alerted when the ship loses connectivity, the associated safety risks can be mitigated.

Regulators should evaluate whether CMASSs used in the RO and AO modes should have fall-back capability to handle necessary communications with authorities and other ships, even under limited or no-connectivity conditions

In UCMASSs, the issue emerges in more pointed terms. With no local crews to serve as backups, the ships have to be able to survive in limited and no-connectivity environments with no outside help. This will require the ships to have a sufficient capability to communicate with both authorities and other ships.

Here, the capability to communicate effectively with VTS providers and pilots and engage in meaningful bridge-to-bridge communications is crucial. Communications with VTS providers and pilots can likely be digitalized. VTS providers could receive the various notifications and issue orders and advise in electronic form, provided that an interoperable communications platform is established. Homogenizing the platforms would likely require that a global IMO guidance document on platform technical requirements is released. IMO should, consequently, develop a platform format and issue a guidance document on electronic communications with VTS providers.

> A framework for digital data exchange with VTS providers should be built.

Bridge-to-bridge communications offer a more difficult challenge. While a similar system for bridge-to-bridge communications between MASSs is conceivable, mixed traffic and MSSs will remain in traffic for decades. Consequently, a system for communicating with human operated non-MASSs will likely be necessary. Here, regulators should ensure that MASSs can communicate with human operated non-MASSs, even when connections to SCCs are severed. This will require exploration on how the communications can technologically facilitated. Regulators will likely have to evaluate whether MASSs should be required to have the capability to communicate with other ships using auditory natural language communication methods.

Regulators should explore requiring MASSs to have the capability to communicate with other ships using auditory natural language.

Other regulatory issues are summarized in Table 10 below.

Table 10. Other regulatory issues.

Regulatory issue	Frame	Regulatory options
Human-ANS interaction	Humans will remain active in MASSs. Rules for humans on MASSs must be drafted.	How should the existence of human backups affect ANS rules? How should ANS technologies affect manning rules? How is accountability for human action on MASSs organized.
Rules on SCCs	SCC will operate RO-MASSs.	SCC technologies, workflows, and staff qualifications must be regulated.
Connectivity, communications and cyber risks	How to ensure adequate connectivity and cyber security.	Use technological regulation to ensure connectivity, communications, and cyber security, and, for cyber risk, institute risk management obligations.
Data protection and sharing	MASSs collect huge amounts of data and need huge amounts of data.	Review data protection rules. Explore methods for sharing data between MASSs and MSSs.
Infrastructures	Infrastructural investments could make operational environments for MASSs.	Explore what infrastructures could make MASS operations smoother (e.g. data sharing by VTS, use of AIS to broadcast path plans.)

4.5. Liability and accountability

4.5.1 Introduction

Sometimes accidents happen. Ships collide, strand, dock awkwardly, or hit submersed objects, resulting in losses and damage. Civil liability rules deal with the financial consequences of accidents, giving victims a right to compensation, and allocating and transporting liability to suitable bearers. Civil liability rules may also have behavioural consequences. They articulate conduct standards and establish accountability for transgressions. This part of the report deals, primarily, with civil liability for MASSs. It explores how the cost of accidents and other failures are allocated by statutory rules and contracts.

To understand the setting, remember that three main civil liability regimes exist. Liability may sound in either tort or contract with product liability providing an intermediate type of liability. Tort liability rules determine who bears the liability for non-contractual wrongs. Contractual liability establishes whether a party to a contract is liable for a breach of contract and how. Product liability rules constitute a third intermediary form of liability that is conceptually in-between non-contractual and contractual liability. Here, producers are liable for the losses and damage their products cause outside contract.

Tort liability rules come in three varieties. The liable party may be:

1) strictly liable for losses caused by them;
2) vicariously liable for losses caused by others for whom they are liable; and
3) liable for losses caused by their negligent conduct.

All three options are relevant in MASS contexts. Shipowners are strictly liable for some losses, vicariously liable for persons working in the service of the ship, and potentially liable for their own negligent conduct.

Contractual liability rules are rarely directly relevant in maritime accident contexts. The rules may, however, become relevant if a breach of contract is related to an accident, triggering the contractual liability of a party. However, existing statutory contract liability rules rarely activate in accidents, as parties to e.g. shipbuilding and ship operation contracts create custom remedy regimes applicable in place of the statutory rules if one of the parties breaches the contract. For example, in shipbuilding contracts it is typically agreed that a party in breach should cure its defective performance within a one-year guarantee window, and that neither party is liable for any direct or indirect losses caused by their eventual breaches of contract.

Product liability rules bifurcate. Producers of defective products, first, are under the Finnish Product Liability Act liable for personal injuries and certain damage to a natural person's personal property, if their product was not as safe as the natural person had a right to expect. For other damage, the liability is based on negligence and the claimant has to show that the defendant caused the damage by their negligent conduct in either manufacturing or designing the product.

The report concentrates on third party damage arising out of accidents involving MASSs. Whether the damage caused by the accidents is recoverable and to whom the liability first falls is primarily determined by tort law rules. However, contractual liability may disrupt the initial allocation of liability if the accident was caused by, for example, a technical failure or malfunction. As contracts often determine who will ultimately pick up the tab, the report also maps out the contractual arrangements underlying MASS construction and operation, and tries to map what impact MASS introduction could have on shipbuilding and operating contracts.

4.5.2 Non-contractual and product liability for MASSs

4.5.2.1 Introduction

This section discusses the non-contractual liability for damage caused by MASSs. The section first discusses how existing strict liability rules may fare in a MASS context. Second, it outlines the problems of collision liability rules. Third, it maps shipowners' vicarious liability for MASS accidents. Fourth, it discusses what shipowners' general negligence liability could look like after MASS introduction. Fifth, it comments on product liability issues. The section is, finally, rounded out by a discussion of whether and how the liability rules should be reformed, in order to address problems that arise in allocating liability for MASS accidents.

4.5.2.2 Statutory strict liability

4.5.2.2.1 Maritime strict liability rules

The strict liability rules relevant in the maritime domain deal with a limited number of specific accident or loss types. Existing statutory strict liability rules pertain to

1) personal injuries;
2) oil and bunker spills;
3) discharge of marine pollutants;
4) costs of wreck removal; and
5) nuclear accidents.

Of the five, the report discusses the first three loss scenarios.

4.5.2.2.2 Personal injuries

Existing statutory rules entail that registered shipowners are strictly liable for death of and personal injuries to passengers they carry on their ships. The strict liability also extends to passengers' luggage and vehicles. While the liability is strict, the victims' right to recovery is subject to the owners' right to limit their liability to statutory maximum amounts. The liability is established by the EU Passenger Liability Regulation (Regulation 392/2009/EU on the liability of carriers of passengers by sea in the event of accidents) that, in turn, implements the 2002 Protocol the Athens Convention relating to the Carriage of Passengers and their Luggage by Sea.

Personal injuries to seamen employed by ships flying the Finnish flag are primarily covered by the Occupational Accidents and Diseases Act, which requires employers to purchase insurance cover for risk of occupational accidents and diseases. Further, owners of industrial equipment are commonly held to be strictly liable for personal injuries caused by safety defects in industrial equipment under KKO 1990:55 and KKO 1991:156, two Finnish Supreme court precedents. While not confirmed by recent decisions, the cases could arguably entail that registered shipowners are liable for all personal injuries caused by safety defects in ships.

4.5.2.2.3 Oil and bunker spills

Chapters 10 and 10a of the Finnish Maritime Code (FMC) contain the rules that establish strict liability for release of oil into the sea. The rules are bifurcated. Chapter 10 rules are based on the 1969 International Convention on Civil Liability for Oil Pollution Damage (CLC Convention) and outline a strict liability approach to oil spills. Under the approach, registered owners of ships carrying oil as cargo are strictly liable for all and any oil pollution caused by their ships, except when a limited number of exceptions apply. The rules also rule out that shipowners' servants, pilots, charterers, or salvors would be liable for the spills.

Shipowner liability under the CLC Convention is, however, severely limited, as the shipowners have a right to limit their liability. If the shipowner limits their liability, the aggrieved party may recover a maximum of 631 SDRs per unit of tonnage or 89,770,000 SDRs in total. The right to limitation falls away if the pollution damage has resulted from the shipowner's personal act or omission, committed with the intent to cause such damage or recklessly with knowledge that such damage is probable.

The limited strict liability regime is buttressed by the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage. The Convention establishes a compensation fund into which all oil importing nations contribute. The fund is complemented by a Supplementary Fund, which is less widely ratified but is applicable in Finland, which pays up to the level of 750 million SDRs per accident.

FMC Chapter 10a implements the 2001 International Convention on Civil Liability for Bunker Oil Pollution Damage. The Chapter 10 a rules replicate the CLC Convention regime for bunker oil spills as far as strict liability is concerned, but the liability is distributed to the owner, operator and bare boat charterer of the ship.

4.5.2.2.4 Marine pollution

FMC Chapter 11 establishes a strict liability regime for marine pollution caused by marine pollutants other than oil carried as cargo and bunker oil. However, while the rules have been promulgated (Act 1401/2019), they are yet to enter into force, and it remains unclear when or whether they will enter into force. Nevertheless, the future strict liability scheme is similar to the cargo oil and bunker oil schemes and implements the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea.

Under the rules, shipowners are strictly liable for discharge of harmful substances into the sea from ships. The liability exists if two conditions are met. Shipowners are, first, liable if harmful substances or effluents containing such substances are "discharged" from ships. The notion of discharge includes "any escape, disposal, spilling, leaking, pumping, emitting or emptying". Second, the discharge must contain "harmful substances" that, if introduced into the sea, are liable to create hazards to human health, harm living to resources and marine life, amenities or to interfere with other legitimate uses of the sea. As with cargo oil and bunker oil spills, shipowners have a right to limit their liability for marine pollutant discharges. The limits are established in FMC 11:5.

4.5.2.2.5 MASSs and strict liability

The strict liability rules are unlikely to cause significant issues during the transition towards autonomous MASS operations. They provide for an explicit and exhaustive allocation of liability: the liability mostly falls on the registered owner of the ship, regardless of whether the owner was negligent or not.

> Strict liability rules are unlikely to cause significant issues in MASS contexts.

Exceptions to the liability are, in addition, limited. The shipowner can typically escape strict liability only if the accident

1) resulted from "an act of war, hostilities, civil war, insurrection or a natural phenomenon of an exceptional, inevitable and irresistible character";
2) "was wholly caused by an act or omission done with intent to cause damage by a third party"; or
3) "was wholly caused by the negligence or other wrongful act of any Government or other authority responsible for the maintenance of lights or other navigational aids in the exercise of that function".

Importantly for MASS contexts, it seems clear that a shipowner would not be able to successfully invoke any of the exceptions if a MASS technological failure resulted in an accident. Cyber-attacks, however, would release the shipowner of liability.

Whether strict liability could constitute a problem for future MASS ecosystems is, however, an open question. As FMC rules mandate that shipowners maintain insurance cover for their third-party liabilities, the possible problems will likely be insurance-related and pertain to which ecosystem actor would be best suited to procure and maintain cover.

4.5.2.3 Collisions

4.5.2.3.1 MSS collision liability framework

The FMC Chapter 8 rules that pertain to damage caused by collisions between two or more ships constitute the second set of liability rules specific to the maritime domain. The rules implement the 1910 Brussels Convention for the Unification of Certain Rules of Law with respect to Collisions between Vessels, and establish a fault-based scheme for assigning liability for collisions.

The default rule is that whoever suffers losses in a collision between two or more vessels bears the losses, if the collision was accidental or caused by a force majeure event. If the collision, however, was caused by the fault of one of the vessels, the vessel that committed the fault bears the liability.

When multiple vessels are at fault, liability is apportioned among the vessels in proportion to the degree of fault committed. In collisions with two or more liable vessels, liability for personal injuries is joint and several. Each ship at fault stands for all losses but has a right of recourse to the other ships in proportion to the fault of each ship. For property losses, each ship is liable to the extent of its fault.

Collision liability rules have a peculiar agency structure. The rules perform the ships as the acting entities that may be at fault for a collision. Despite the seeming ship anthropomorphism of the rule wordings, scholars have held that the ship is a look-through entity. The fault assessment focuses on appraising whether and to what extent the negligent or wilful conduct of the master, crew or shipowner contributed to the accident.

4.5.2.3.2 MASS collisions

The collision liability rules focus, despite their apparent ship-centricity, on human failures and shortcomings. This renders the rules inherently and fundamentally problematic in non-human controlled MASS contexts, while human controlled MASSs are likely to fare better.

In human-controlled MASSs, fault assessment can likely continue virtually unchanged to the degree that immediate human action contributed to the accidents. If the local crew or SCC staff was at fault, the ship is at fault.

If a technological failure is the cause of an accident, things will change. The fundamental feature of non-strict liability assessment becomes visible. Liability standards are conceptually impaired to resolve "non-human" wrongdoing. In collision liability, the conceptual impairment leads the fault assessment to revert back to appraising the conduct of those who exercise control over the ship. Those people have, however, largely disappeared and been replaced by other people who are only indirectly involved. Lines of causation turn fuzzy and responsibilities become unclear.

> Fault-based liability standards will become problematic in autonomous systems.

The distinctive features of MASS software are the source of these troubles. As Collin (2018) has pointed out, many code components in autonomy system will be closed black boxes that will remain opaque to their users. Even if the algorithms would be open source, most MASS "end users" would lack the resources required to inspect the algorithms thoroughly. Thus, establishing that someone was at fault will become an elusive undertaking. Pursuing the meta level actors may often be useless.

Requiring, for example, that inspections, capable of detecting the eventual defects or bugs, are carried out will likely be an infeasible burden on all involved parties, masters, crews, and shipowners alike. These parties will not have a realistic opportunity to discover the defects and, consequently, MASS accidents are likely to increasingly fall into the black hole of the collision liability rules. Collisions will have technical causes that neither the master, the crew, nor the shipowner could be reasonably expected to detect beforehand. The logical conclusion is a finding of no fault, which would lead to victims receiving no compensation.

> Collisions will increasingly have technical causes that no reasonable party could have identified beforehand, making an at fault party impossible to find.

The other option is that we mangle fault assessment beyond recognition, impose impossibly demanding inspection duties, and turn the *de jure* fault liability for technological components into a *de facto* strict liability.

It could be argued that the conundrum is not novel. Collisions have been caused for centuries by lacking technical seaworthiness. Doctrine has developed tools to assess whether the master, the crew, or the shipowner contributed to the ship's unseaworthiness by their wilful or negligent conduct. In some jurisdictions, courts have imposed a *de facto* strict liability on shipowners for technical failures, thus creating a precedent for the MASS case. A *de facto* strict liability standard would be technically unproblematic in MASS contexts, if adopted. The standard would entail that if an autonomy technology failure, either in the systems' mechanical parts or code components, caused the accident, the ship would be held at fault, protecting aggrieved parties.

> Interpreting the statute to provide for *de facto* strictly liability could ameliorate the problem, yet be intellectually dishonest.

A third option, however, potentially exists. The template is provided by the Finnish Traffic Insurance Act (FTIA) 33 §, dealing with collision damage to vehicles. The basic principle underlying the FTIA is that vehicle owners receive no compensation for damage to their vehicles from the compulsory traffic insurance, if another vehicle party to the collision was not at fault for the collision. A party, then, is at fault if one of three conditions is met:

1) the driver or the passenger of a vehicle caused the accident by negligent conduct;
2) the movement or the position of the vehicle did not comply with traffic rules; or
3) the vehicle was in defective condition or cargo was stowed inadequately.

A similar approach to the FMC Chapter 8 notion of fault seems to comply with at least the literal wording of the rules and, thus, keep FMC Chapter 8 fault assessment alive. A ship, whose movements or position is non-compliant, is at fault in the sense that it caused the accident. The approach has its problems, however. First, as recounted above, the COLREGS rules contain multiple vague and open-ended provisions, which may make it challenging to assess when the ship's movement or position was or was not compliant with the rules. Second, as the FMC Chapter 8 rules implement the Brussels Convention, explicit changes to the FMC wording would either require an amendment to the Convention or that Finland denounce the Brussels Convention. Courts could, nevertheless, adopt a FTIA 33 § inspired standard as their standard interpretation for fault in collision cases.

4.5.2.4 Shipowners' vicarious liability

4.5.2.4.1 Vicarious liability under FMC Chapter 7

The strict liability rules cover a relatively wide range of losses and accident types. The registered shipowners are liable for damage from oil and bunker spills, (pollutant discharges) and many, but not necessarily all, personal injuries. Similarly, the shipowners are liable for collision-related losses if the ship was at fault for the collision. Nevertheless, other accidents and damage remain beyond the coverage of such special liability rules.

The vicarious liability rule is contained in FMC 7:1. The rule provides that the reder is vicariously liable for losses or damage caused by the errors or omissions of the ship's master, crew, pilot, or other non-crew member party who is working for the account of the ship on assignment by the functional ship owner or the master. The "error and omissions" standard is comparable to that found in Finnish Tort Liability Act (FTLA) 2:1, i.e. requires that the damage was caused by a negligent action or omission.

The FMC stays mum on who are reders. The concept does not fixate on ownership, but attaches liability to the control exerted over ship safety matters: a person or an organization that has assumed effective responsibility for matters relating to the safety of the ship, whether the de jure owner or not, is considered the reder. The concept, thus, covers owners that operate the ship, but also extends to, for example, bare boat charterers.

4.5.2.4.2 Vicarious liability and MASSs

In MASS, the vicarious liability scheme will likely become strained. As manning is reduced and the crew ultimately eliminated altogether, the shipowners and charterers and other vicariously liable parties will directly employ increasingly fewer people to operate the ship. The people who are involved with operating the ship will also have an increasingly tenuous connection with the ship. They might be geographically removed from the ship, working in SCCs, or perform duties that are unrelated to the immediate operation of the ship as they develop the autonomy equipment.

As FMC 7:1 provides that the shipowner is vicariously liable for the errors and omissions of the "ship's master, crew, pilot or another non-crew member persons working in the account for the ship", two important questions arise in MASS contexts: whether the SCC staff and the autonomy equipment providers' employees fall within the scope of the shipowner's vicarious liability.

For SCC staff, the question seems relatively unproblematic. The staff should, regardless of their status as mariners, be covered by the rule in FMC 7:1. The staff indisputably works in the service of the ship, performing the typical activities that operating a ship requires, although from ashore. Consequently, there is no reason to treat SCC staff differently from the master, the crew, the pilot other persons working on MSSs.

> SCC staff will likely fall under the vicarious liability rules in FMC 7:1.

A problem might, however, emerge in relation to dedicated FCC companies. These companies might be considered functional shipowners, if they exercise effective control over ship safety matters. Such an interpretation could force companies offering SCC services to carefully draft the service contracts to evade shipowner status.

The position of autonomy technology providers' employees raises the second set off concerns. Although Finnish courts have seldom ruled on questions related to the FMC, it is clear that a person covered by FMC 7:1 must be working in the service of a particular ship. This interpretation likely prevents courts from holding that the rule in FMC 7:1 applies to the employees of autonomy equipment providers. If the employees develop and work on systems that see or are designed to see use on multiple ships, the "on account of the ship" prong of the test in FMC 7:1 is not met.

FMC 7;1 also requires the work performed to be a typical activity connected to operating a ship. This has been held to exclude, for example, the errors and omissions of repairers and yard employees from the scope of the shipowner's vicarious liability. The work done by autonomy provider employees resembles the work done by e.g. repairers, further buttressing the argument that the employees would not be covered by the FMC 7:1 language.

ANS developer employees will likely not fall under the vicarious liability rules in FMC 7:1. But, as FMC is national legislation and not controlled by international conventions, modifying the wording would be possible.

4.5.2.5 Shipowner negligence

4.5.2.5.1 The fallback Finnish Tort Liability Act rules

While the strict liability rules and shipowners' vicarious liability cover a considerable degree of conceivable maritime accident scenarios, some losses may, nevertheless, slip through. In these cases, general tort law provides the fallback rules.

Here, FTLA 2:1 contains the primary rule to be applied. According to the section, tortfeasors must compensate all losses they have caused by their wilful or negligent conduct. In the maritime context, the rule would primarily apply to shipowners' conduct as the shipowners exercise control over the ship.

Cases that pertain to shipowners' liability specifically are few in the Finnish courts. Thus, there is little material to work with to develop an understanding of FTLA 2:1 in the maritime contexts. The only option is to turn towards the general tort law doctrine.

In the doctrine, negligence assessment is often portrayed as encompassing one of two available heuristics for assessing whether the tortfeasor caused the losses negligently. A person is held to have acted negligently if they did not comply with an existing relevant behaviour rule when compliance with the rule would have averted the accident. This variety of negligence assessment is known as rule-based negligence assessment. The other option, triggered if no applicable rule can be found, is to conduct a risk-based negligence assessment. The US Learned Hand formula provides the template for the risk-based assessment, although likely in a modified form. The alleged tortfeasor will be found to have acted negligently, if the costs of the measures required to avert the accident would have been lower than the expected utility of implementing the measures. Here, conceptions differ. Some scholars have argued that risk-based negligence assessment requires directly comparing the cost of precautions to their utility, while others stress that the standard is not a test but a heuristic. Some scholars have also argued that the risk-based negligence assessment, in fact, requires the tortfeasor to undertake all reasonable precautions to avert the accident (Viljanen 2005; Hemmo 2005; Virtanen 2011).

Here it is worth to bear in mind that under Finnish law, finding that the alleged tortfeasor's conduct was negligent, requires that the alleged tortfeasor, in fact, could have averted the accident. As often stated, negligence-base tort law rules impose liability for making wrong choices and causing damage, not merely for causing damage.

4.5.2.5.2 Negligence and MASSs

As with collision and vicarious liability, standard fallback negligence-based liability rules seem likely to become problematic in MASS contexts, in particular when accidents are caused by technology failures. Here, the problem is, again, that shipowners may have no realistic opportunity to detect technology defects before they cause an accident.

> As with the fault based collision liability, MASSs may disrupt negligence assessment, for similar reasons.

4.5.2.6 Employee liability

The preceding discussion has mainly pertained to the liability of shipowners, who, in most cases, are corporations. A framing of civil liability rules that would seek to stress the accountability function of the rules, would, doubtlessly, also explore the shipowners' employee's liability for maritime accidents caused by the employee.

Here, Finnish tort law rules protect employees. FMC 7:1 provides that if the tortfeasor for whom the shipowner is vicariously liable is also liable, the aggrieved party may only claim damages from the tortfeasor to the extent they were unable to get compensation from the shipowner. Employee's liability is further limited by FTLA 4:1. The tortfeasor is only liable to extent deemed fair. In cases where the damage was caused by slightly negligent conduct, the aggrieved party will receive no compensation from the tortfeasor. The tortfeasor is, however, liable to compensate the losses caused by their conduct to the shipowner, but the quantitative extent of employee's liability is limited by the same rule in FTLA 4:1.

Employees are rarely directly liable for accidents they cause.

Consequently, tort liability rules are relatively weak as deterrents. The weakness entails that tort liability is not and will not be an effective instrument for pursuing crew member accountability. Instead, the FMC and Penal Code criminalizations provide whatever legal accountability mechanisms exist.

4.5.2.7 Product liability

4.5.2.7.1 The product liability framework

Product liability sits in between contractual and non-contractual liability. The rules bifurcate. On the one hand, product liability may exist pursuant to The Finnish Product Liability Act (FPLA) rules, on the other hand, it may arise from non-contractual rules. The discussion will start with a charting of product liability under the FPLA.

FPLA makes producers, those who produce industrial products or import them into EU or EFTA, liable for certain damage defective products cause. The notion of producer includes both the manufacturers of a final product and the manufacturers of the component that in included in the product. Thus, in the shipbuilding context, both the shipyard and the shipyard's suppliers could end up liable for a defective ship. For example, if a ship propulsion system is defective and causes the ship to collide with a yacht, both the shipyard and the propulsion system manufacturer could potentially be liable.

Not every industrial product is considered a product, though. Software is typically not considered an independent product under the Act or the EU Product Liability Directive (PLD) the Act implements. Therefore, software developers who only sell software will likely escape product liability under the current rules.

This does not, however, entail that aggrieved parties will automatically be denied compensation if software causes an accident. Losses caused by safety detects in software are recoverable, if the software constituted an integral part of a physical product, for example a part of its operating system, and caused the product to be defective, which, in turn, caused harm to protected interests. For example, the manufacturer of a computer could be liable for a defect in the computer's operating system if the defect causes the computer to catch fire, and, then, the owner's house to burn down. However, even here the compensation would be payable only by the manufacturer of the physical product, not the software developer. (See e.g. Howells, Twigg-Flesner, and Willett 2017)

The notoriously vague language in FPLA Section 3 provides that the producer of a product is liable if the product is defective, i.e. when it does not provide the safety which a person was entitled to expect. The standard often leads to highly contingent and ad hoc decision-making.

While the standard is broad, the Directive allows producers to file a development risk defence. Under the defence, producers escape liability if they can show that "the state of scientific and technical knowledge at the time when (the producer) put the product into circulation was not such as to enable the existence of the defect to be discovered". For defects in MASS algorithms, the development risk defence is, however, unlikely to be effective, as most algorithmic defects are per se discoverable.

PLD Article 15, however, also permits a member state not to allow the development risk defence. Finland has availed itself of the opportunity and opted to hold producers liable, even if they prove that the state of scientific and technical knowledge, at the time when he put the product into circulation, was not such as to enable the existence of a defect to be discovered.

To counter for the stringent liability ground, the FPLA has a limited substantive scope. FPLA Section 1 provides that the Act covers death and personal injuries caused by products. In addition, the Act covers damage to and destruction of property that, 1) is of a type ordinarily intended for private use or consumption, and, 2) was used by the injured person mainly for his own private use. This limitation entails that a range of maritime losses will fall outside the FPLA purview. If an accident causes damage to or the destruction of commercial property, the loss event will be governed by general tort liability principles. The principles are, to a largely degree, unsettled, but the liability sounds in negligence. To recover their losses, the aggrieved party must show that the manufacturer acted negligently while designing or manufacturing the product.

4.5.2.7.2 Product liability in maritime contexts

In the maritime contexts, a number of product liability issues remain unclear (E.g. Collin 2018). First, it is unclear whether the shipowners' right of limitation under FMC Chapter 9 rules extends to product liability losses. The wording of the rules in FMC Chapter 9 is unfortunate in this respect. FMC 9:1 provides that shipowners and other parties who, in the shipowner's stead, operate the ship have a right to limit their liability. Section 2, in turn, provides a list of receivables in relation to which liability can be limited. Limitation right exists regardless of the legal ground of the receivables.

Implications of product liability rules in maritime contexts are uncertain.

A systematic reading of the two rules should lead to the conclusion that the FMC rules only allow the parties mentioned Section 1 to limit their liability, and only for the receivables mentioned in Section 2. This interpretation would entail that FPLA producers would have the right to limit their liability only if they were Section 1 parties. Consequently, most producers would not be able to appeal to the FMC Chapter 9 rights.

As producers likely have no right to limit their liability pursuant to the FMC rules, a fractured liability landscape will likely emerge. Maritime sector specific liability rules offer aggrieved parties an easy avenue to recovery for personal injuries, as well as oil and other pollutant related damage. For other losses, the bar is higher. To meet the requirements for recovery, the aggrieved parties must show negligent conduct by either the shipowner or those for whom the shipowner is vicariously liable. Compensation is, in both cases, limited by the global liability limit rules. If the accident was caused by defective equipment, the aggrieved party will likely, under the FPLA rules, have an avenue to pursue quantitatively unlimited redress, but faces the burden of proving that the ship was not as safe as a person has entitled to expect. Whether the same applies to product liability claims that are not sounding in the FPLA rules is unclear.

Second, as product liability rules apply to importers who have imported the product into the European Union or the European Free Trade Area for sale, hire, leasing or any form of distribution in the course of their business, a shipowner who brings a vessel into the EU might be considered a producer. Here, the wording of the rule creates a risk of an uneven playing field. Shipowners that do not sell the ship but operate it themselves do not fit the importer test that is set forth in the Act. Such shipowners have not imported the ship for distribution. Shipowners who charter or sell ships, however, would likely satisfy the test.

4.5.2.8 Product liability and MASSs

MASSs cause serious problems for product liability. First, significant doubts have been expressed over whether the EU PLD, in particular, is fit for the new digital age. Problems are caused by the increasingly digital, software-mediated mechanisms of harm generation. Products increasingly contain software components that harm users. Importantly, as robots start escaping the confines of their industrial cages, also physical harm will ensue. (See e.g. Meeus 2019; Bureau Européen des Unions de Consommateurs 2020; Wagner 2018)

Several detailed concerns emerge in relation to MASS accidents. First, as software is not a fully-fledged product, an apparent liability gap opens up. Even if product manufacturers are liable for damage caused by software, software developers appear to escape scot-free when their software proves defective. This may jeopardize the deterrence value of product liability. However, the gravity of such damage would be unclear, as there is little evidence that product liability would be efficient in encouraging producers to ensure that their products are safe.

> As software products are currently not considered products, product liability may struggle in MASS contexts.

The software liability gap is a potential problem in MASS contexts as well. It may become a pressing issue if MASS software becomes uncoupled from autonomy equipment. Suppose that a shipowner procures a software for a new autonomous navigation system from a software vendor and installs it on their ship, which, then, proceeds promptly to strand in fair weather conditions for an unknown reason, damaging third party interests covered by the FPLA. Under the current FPLA rules, the aggrieved parties would be barred recovery from the software developer. There would effectively be no product liability, lest the aggrieved party manages to show that the developer should be liable under normal tort liability rules. (See e.g. Howells, Twigg-Flesner, and Willett 2017; Collin 2018)

Third, even with no potential liability gaps, safety defect assessment will be challenging in MASS software failure cases. As the Act and the PLD peg liability to the ambiguous "does not provide the safety which a person is entitled to expect" standard, court safety assessment may devolve into an unpredictable cacophony of contradictory *ad hoc* rulings (Collin 2018). Fourth, in countries where the development defence is available, the scope of product liability coverage may be unclear until case law settles how extensively the defence will be applicable in software contexts.

Product liability rules are often justified by appealing to their alleged regulatory effects. Advocates of product liability argue that the rules contribute to regulating the industry and induce the industry to implement safer designs. The argument presupposes that the threat of liability will incentivize safety investments. Whether and under what conditions the theory may hold, is an open question (Geistfeld 2017).

> Safety defect analysis will be challenging and potentially costly in MASSs and the concomitant "regulation-by-trial" strategy may be ineffective.

4.5.2.9 The future of maritime non-contractual liability

4.5.2.9.1 A fractured landscape

The end result is a fractured future liability landscape for MASS accidents, accountability, and the resulting third-party losses.

The current maritime liability framework is a convoluted amalgam of approaches of varying pedigree, vintage, and conceptual structure. In addition, parties often use contracts to modify the liability landscape by reallocating liability among themselves, although here the possibilities are limited.

The existing specific maritime domain rules will impose a strict liability on owners of MASSs for most personal injuries. Victims of small-scale oil and bunker spills, and, in the future, marine pollution, are similarly well protected. In large scale accidents, damage may, however, go uncompensated due to the shipowners' right to limit their liability, with governments ultimately picking the tab if the accident was not caused intentionally or grossly negligently. MASS introduction does not disrupt these rules or their application. They are MASS-ready.

For other loss events, things are different. Recovery opportunities may be growing increasingly patchy as MASSs are introduced. If autonomy technology has failed and caused an accident, MASS introduction may create cases where no one is found guilty of negligent conduct, but where similar non-MASS accidents would, inevitably, have had a cause in someone's negligent conduct. In consequence, damage that we have grown to expect would be compensated, may increasingly go uncompensated.

4.5.2.9.2 Hard questions

The possible liability gaps, together with the strict liability standards, raise hard questions about the purposes of tort law rules in the maritime context.

a) Disrupting compensation patterns

Tort law rules exist to ensure that aggrieved parties receive compensation (compensation function) for their losses if someone else causes unlawful damage.

The introduction of MASSs may disrupt the existing compensation (in)equilibrium. Negligence liability, the prior main fallback regulatory instrument used to apportion loss incidents into compensable wrongs and pure accidents, is under a threat of becoming dysfunctional. The reason for the looming dysfunctions is that negligence is an inherently human notion. It best governs domains where humans are immediately present and make choices over what course of action is taken. In MASS, the humans, however, are nowhere to be found. This pushes negligence assessment towards its limits. If negligence withers away as a feasible risk and loss allocation tool, liability gaps may appear, and the established maritime risk allocation patterns are shaken.

> MASSs may disrupt the compensation patterns as fault based liability is poised to disintegrate.

b) Losing behavioural control

Tort law rules are also used to control behaviour (behaviour control function). Tort liability institutes a conditional cost on undesirable activities, and, consequently, creates incentives not to cause harm to others. At the same time, tort law creates a venue for pursuing accountability: those who commit wrongs, must answer them.

Our wish to regulate behaviour and pursue accountability with tort law rules explains why negligence is the primary tort law standard. We want to discourage careless conduct that could result in a person infringing the rights of others. Negligence provides the device that is capable of doing exactly that, as it expands rule coverage to unanticipated and unprecedented cases, and is capable of articulating what should have been done in any conceivable case, albeit sometimes *ex post facto* and often quite unpredictably.

In MASS contexts, the goal of regulating behaviour translates into a requirement that whatever the future liability rules will be, they should encourage reasonable, socially desirable conduct and discourage reckless risk-taking. Whether this is the case at the moment is debatable. The accountability that liability rules – and other rules – create in maritime contexts seems halting at best. As recounted above, employees escape often with little or no civil liability. While FMC Chapter 20:2 criminalization buttresses deterrence, accountability may still prove elusive. While masters face heavier penalties if they fail to ensure seaworthiness, accountability may remain feeble. The same is true of reders, their liability for accidents, and the FMC 20:1 based criminal liability for failures to not allow ships depart port if unseaworthy. The reders' civil liability is toothless, especially after taking into account the extensive insurance coverage shipowners have. While criminal law penalties are relatively stiff, they will likely add little deterrence.

With MASSs, things will not improve. As immediate operational choices recede and are replaced by ambiguous hard-to-trace metalevel technology choice decisions, the existing rules will likely lose much of their current traction as regulatory instruments. The negligence-mediated regulatory pathways clog up. Involved parties face information shortages and must make decisions essentially blind. This reality fits poorly with the assumptions underlying both civil and criminal liability standards.

Behavioural regulation through tort and criminal law will also likely become a pipe dream. The courts would be required to articulate how algorithms should be designed, but they are clearly too slow, cumbersome, and low-resolution decision-makers to effectively govern the MASS design processes. Regulation by trial will fail. Thus, tort law rules lose their legitimacy that flows from their effects as behavioural contract tools.

> Tort law is at best a poor behaviour control tool. It will likely lose more of its traction in MASS contexts.

For accountability, the story may prove similar. While shipowners could, theoretically, be liable both in tort and criminal law for their failures to ensure that ship systems are adequate for safe operations, the considerable evidentiary burdens plaintiffs are likely to face and the shipowner's insurance cover will blunt efforts at ensuring accountability.

While things may look bleak, the increasing reliance on technologies may, paradoxically, also prove a blessing. It will likely reduce the need for liability and accountability. If regulators succeed in building a functional regulatory framework, and the performance of MASS technologies is conscientiously tested and inspected by firms and classification societies, the opportunities for human errors and wrongdoing decrease. The effect might extend to the processes that remain in human hands such as maintenance. The technological components will monitor themselves and alert if human errors and omissions are about to unfold.

c) Internalizing costs

Tort law is also understood as a tool that, at times and often haltingly, internalizes externalities and, thus, allocates the social costs of a risky activity to the party who is considered best fit to bear them (social cost allocation function). If and when negligence collapses, externalities may go uninternalized. Shipowners get to operate ships and cause accidents with seeming impunity if the losses are not covered by the strict liability rules. Correcting this shortcoming may require regulatory action.

d) Symbolic function

One should not discount the symbolic significance of tort law in sustaining the illusion of accountability, moral responsibility, and legitimate distribution of risks. Negligence liability allows us to identify and castigate culprits, be they, in fact, scapegoats with no real control over the processes they have become entangled in, or real blameworthy tortfeasors. This likely explains why the liability rules persist and are deemed useful, despite many studies having highlighted that social and liability insurance have rendered negligence liability an inefficient and nearly irrelevant tool of rational societal governance. With MASSs, the ugly truth that much of our liability laws are dysfunctional and serve no real purpose in regulating behaviour may finally become visible and impossible to suppress.

e) Product liability trouble

Product liability rules add to the fractures in the liability landscape. They will, potentially, destabilize the shipowner-centric liability patterns as, in robotic contexts, the rules provide the aggrieve parties an avenue to seek compensation. The avenue runs parallel to the shipowner-centric liability regime, and, importantly, there is little that producers can do to close it. Under FPLA rules, aggrieved parties with protected interest will always have the right to pursue compensation, notwithstanding contractual undertakings to the contrary. As it is unlikely yet somewhat unclear whether producers can avail themselves of the shipowner's right to limit their liability, product liability could be potentially unlimited in quantitative terms. In particular, for environmental damage, any liability could be crippling to producers.

f) Insurance concerns

Insurance provision provides another cause for concern. The liability status quo allows for efficient insurance provision. As shipowners are de facto almost exclusively liable in maritime accidents, the costs of such accidents can be covered by a single insurance policy that the shipowner maintains. In addition, the shipowner protection and indemnity policy terms are essentially subsidized by the statutory right of limitation. In MASS contexts, the insurance landscape may recombine. Producers may have to purchase policies to cover their potential product liability towards third parties, lest they wish to accept the risk of incurring potentially debilitating payment obligations. To make matters worse, all actors in the autonomy value chain could need a product liability policy of their own. This could lead to situations where actors in the value chain purchase multiple overlapping policies that cover the same risk.

Autonomy value chain actors have limited leeway to contract around the liability problems. Producers and component producers could include in the supply contracts terms that allocate product liability risks to a suitable actor in the value chain. The contracting could extend to cover the interface between the shipowner and the final ship producer. However, as third parties have direct claim rights to all value chain actors irrespective of the contracts between the value chain actors, insolvency risks and opportunistic use of bankruptcy rules will continue to mar the risk allocation contracts. Whatever the parties agree on concerning who will ultimately bear the product liability, the agreements will provide protection only if the party to whom the liability was allocated is willing and able to honour its obligations.

b) Right to limitation of liability

Finally, the 1976 Convention on Limitation of Liability for Maritime Claims grants shipowners the right to limit their liability for Maritime Claims. Under the amendments to the 1996 Protocol, the limits cap the shipowners' liability for loss of life or personal injury on ships not exceeding 2,000 gross tonnage to 3.02 million Special Drawing Rights and, for larger ships, to 1,208 SDR for each ton from 2,001 to 30,000 tons, to 906 SDR for each ton from 30,001 to 70,000 tons, and to 604 SDR for each ton in excess of 70,000. The limit of liability for property claims for ships not exceeding 2,000 gross tonnage is 1.51 million SDR, and for larger ships, 604 SDR for each ton from 2,001 to 30,000 tons, 453 SDR for each ton from 30,001 to 70,000 tons, and 302 SDR for each ton in excess of 70,000 tons. Other higher limits are set in *e.g.* the CLC Convention and Athens Convention (250 000 SDR per passenger) for specific claim types.

The right of limitation has long historic roots and has to date proven impossible to discard. MASS introduction might provide the impetus for revoking the institution and requiring the shipowner to bear the externalities caused by their activities in full.

4.5.2.9.3 The way forward

Consequently, MASS introduction may lead to a situation where we will have to reimagine what we should try to do with tort law rules. Clinging on to "real" negligence assessment and the behavioural control function of tort law would require us to develop a tool capable of articulating when and on what conditions indirect, organizationally and temporally diffuse action is undesirable. Tort law and its concomitant "regulation by trial" strategy is a poor instrument for regulating design and innovation processes and, consequently, an insufficient solution to regulatory problems that emerge in MASS contexts. In addition, adopting the strategy would likely entail that MASS owners would gain a processual advantage. Claimants would be burdened by, first, the inherent evidentiary difficulties that arise when outsiders attempt to gain information on and understand organizationally and temporally diffuse intra-firm processes. The costs of the suits would also likely be prohibitive, in particular, in jurisdictions where punitive damage awards are not available. The processual difficulties would likely in fact entail that shipowners would be able to impose externalities on third parties.

Imposing strict liability on shipowners for all MASS related would likely be the simplest approach to organizing liability for MASSs. Thus, the behavioural control and symbolic functions may have to be discarded. What will remain are compensation and social cost allocation functions. Both advocate for clear-cut rules that allocate liability to parties who deserve to bear it: the owner who ultimately reaps the financial benefits of operating the ship. Consequently, the report recommends that registered owners be made strictly liable for the damage MASSs they own cause. The unambiguous risk allocation provides an easy starting point for parties to reallocate the risks. An unambiguous allocation allows parties to use contractual allocation tools, while securing aggrieved party interests and allocating the costs to the party who should bear them.

4.5.3 Contract and contract transformations

4.5.3.1 Introduction

Contracts and contractual liability constitute a second liability flash point. As crew numbers are reduced, navigational functions can either be performed by technological systems or transferred to SCCs. In UCMASSs, taking care of cargo during the voyage will have to be a technological process, while cargo handling could be tasked to onshore agents. In UCMASSs, maintenance operations will have to move onshore and to shipyards, and technology providers will have to make significant investments in improving reliability and driving down the ship's maintenance needs. The same pressures are likely present in CMASS with reduced crews.

These transformations in how different functions are performed will have an impact on the contracts and contracting patterns used in operating ships. While the effect of crewing changes is easy to spot in relation to the contracts governing the ship's trading phase, the repercussions will likely spill over to the construction phase as well.

In the following, the report will discuss the possible transformations and their significance. The report will explore

1) how contracts governing ship operations may change, and
2) what implications MASS introduction may have on ship construction contracts.

4.5.3.2 Contracting for SCC operations

4.5.3.2.1 Organizing SCCs

Remote operation will likely be the first commercial use that MASS technologies will see. SCCs may replace in the near-term future the crews in RO-CMASSs. The first obvious contract related question is, thus, who will manage the SCCs and how will SCC operation be contractually governed.

Multiple options likely exist. First, shipowners could operate their own proprietary SCCs for their MASS fleets. Second, novel dedicated SCC service providers could emerge to offer SCC services to shipowners. Finally, MASS technology manufacturers could operate the SCCs (the manufacturer alternative).

> SCCs may be run by shipowners, service providers or manufacturers.

At present, we may only speculate on how the industry will be structured. However, as building a SCC will likely require considerable technology investments, shipowner operated SCCs may be economically feasible only if the shipowner's fleet is sizable.

SCC service providers, on the other hand, would be poised to capture the benefits of the economies of scale. They could offer their services to multiple shipowners. Here, however, technological diversity in MASS equipment could complicate operations and require sizable investments in both technology and human skills to facilitate multiplatform operations.

Autonomy equipment manufacturers could also offer SCC services for their installed base. This could be an attractive option enabling the manufacturers to leverage their technological expertise but, simultaneously, boost technological lock-in effects. The model would, however, require that manufacturers transition from a technology product business to providing navigational services, a potentially difficult transition to a new line of business.

4.5.3.2.2 Contractual implications

The contractual implications of the various operational alternatives are difficult to chart. If shipowners operate in-house SCCs, it is conceivable that no perceivable changes take place. The model is largely comparable to the current in manned ships. The shipowner employs the SCC staff like it would employ the crew and is, doubtless, vicariously liable for their actions.

For the dedicated SCC service provider option, the picture is, however, muddier. The contractual structures will likely hinge on whether the SCC companies function as crew management companies or crew selection and management agents, or offer genuine SCC services, including navigation. The latter option seems more likely due to the infrastructure investments that SCCs require.

If the SCC service providers provide genuine navigational services, the shipowner and the SCC service provider could enter into a contract where the SCC service provider undertakes to navigate the ship for a fee. Here, the interface with marine insurance may become problematic. The standard London market for named risk hull and machinery policies cover the negligence of the masters, officers, crew, or pilots, but contain no language that could accommodate navigation service providers. Consequently, the policy language would have to be updated to facilitate continuation of coverage.

For the crew selection and management option, the contracts would appear to retrace traditional agency contracts with the added complications offered by having the crew, possibly, work using the SCC company's equipment and on the company's premises. The SCC service option would likely result in the parties using service contract templates. In this option, coordinating the interface between the SCC service contract and the ship's insurance policies is crucial.

The manufacturer alternative will likely be contractually similar to the SCC service contract option outline above, with the same insurance concerns.

> SCCs could destabilize existing patterns of ship operation contracts.

4.5.3.3 Contracting for autonomous operations

4.5.3.3.1 Organizing autonomous operations

Another interesting contract-related question pertains to how manufactures will offer autonomous operation technologies to customers. Three options seem conceivable.

> MASS technology could be offered as products, services, or using a hybrid approach.

MASS technologies could be offered as traditional products. In this alternative, the manufacturer would sell its technology to the shipyard or the shipowner on product offering terms. Contractually, this would entail that the manufacturer would sell the equipment, undertake to cure defects within a set guarantee period, but, importantly, assume limited or no liability for defect-related losses that the buyer may incur. Importantly, the manufacturer would have minimal involvement in operating the equipment as, in product offering models, the end user bears the responsibility for operating the equipment.

Four possible contractual arrangements could emerge. In a clean newbuild scenario, the manufacturer could, first, sell its equipment to the yard which, then, would install it on the ship and sell the finalized ship, including the autonomy equipment, to the shipowner. Second, the equipment could be procured as a newbuild retrofit, with the shipowner buying it directly from the manufacturer and engaging the yard to merely install it. Similar scenarios are conceivable for traditional retrofits. Autonomy equipment could fall within the scope of the yard's delivery obligations in a clean retrofit scenario, while the yard would only perform contracted installation work in an installation-only retrofit.

MASS technologies could also be offered as a service offering. In this case, the equipment manufacturer or the software developer would charge a periodic fee for providing a navigational service to the shipowner.

The third option would be a hybrid of the two previous approaches. The technology would be sold to the shipowner, but the manufacturer would offer the software, that is operational services, separately.

4.5.3.3.2 Product offering contracts

In product offering models, four concerns may be of note. Product offering contracts typically transmit stable goods from the seller to the buyer. This is not the case for MASS autonomy equipment. Autonomy equipment software must be managed and updated. The first concern is therefore, the complications caused by MASS in the contractual arrangements between the yard, its supplier, and the future end user. The end user would likely have to enter into a contract, governing the software update process, with the manufacturer or software developer, regardless of who sold the equipment. This will increase contract complexity, in particular in the clean newbuild and retrofit scenarios.

> Product offering model may be problematic as shipowners will likely have little control over ANSs.

Second, in the clean newbuild scenario, a yard buying the autonomy equipment for installation exposes itself to product liability claims. Product liability rules entail that the yard is likely to be considered a producer of the ship, including the autonomy equipment. The equipment manufacturer would not escape scot-free as they would be considered a component producer. The exposure would force the yard to carefully assess whether it is willing to and bear the product liability risks or rather transfer them to e.g. the manufacturer or an insurer. The latter options will require new contractual arrangements.

Third, the navigational software source code will likely be contained within a closed black box, as the algorithms constitute the manufacturers' primary software assets. Closing the code will, first, likely entail that neither the yard nor the shipowner have a feasible opportunity to genuinely inspect the product and assess its quality prior to the purchase decision. Even if allowed access, the shipowners or operators would, second, likely lack the necessary resources and skills to evaluate the code. Third, all parties, except the manufacturer, will be equally incapable of addressing any possible flaws and malfunctions during operations. The end users will, consequently, be at the mercy of the manufacturer. The end users would, thus, have an interest to make sure that they have recourse to the manufacturer or the developer.

Finally, one should bear in mind that autonomy equipment will perform safety-critical functions, often with no human backup layers available on board. Defective equipment will cause accidents, which in turn will trigger drastic responses from authorities. Eventual decertification of autonomy equipment would entail that the ship would not be able to operate until the autonomy equipment is re-certified after fixes or a replacement system is installed. Consequently, to attract customers, autonomy equipment manufacturers may need to guarantee the usability and performance of their devices. This may require considerable capital resources.

Shipowners could insist on having recourse to manufacturers for possible ANS failures.

Whether a product offering model would, in the end, be feasible for autonomy equipment, is an open question. The report, however, surmises that product offering models may be infeasible and, consequently, service offering centric models may dominate the industry going forward.

4.5.3.3.3 Service-offering contracts

While service offering models have proliferated in recent years, also in the industrial business-to-business space, the contractual templates still remain in flux. This is, in part, due to incomplete servitization. Most industrial service business models have focused on leveraging auxialiary services, such as maintenance and support instead of offering the primary technologies as a service.

Service contract models for high risk, safety-critical technologies are unproven.

Providing high value, high risk, and safety-critical navigational services through servitizing the technologies seems, thus, a qualitatively novel and radical proposition. As recounted above, the services will be critical both to shipowners' business continuity and MASS safety. Malfunctioning navigational equipment or code in an AO-MASSs result in a total loss of the ship and great third party losses.

While the same pattern could be said to hold for, e.g., maintenance services, the conceptual space is different. First, maintenance services have established quality assurance practices and diligent owners can easily employ an expert and task them with inspecting the maintenance outcomes and detecting shortcomings. Second, the master and the crew provide ultimate line of defence on MSSs. Both of these will be absent in MASSs, leaving the ship's fate entirely reliant on the technologies.

Providing an autonomous operation service equates taking full operational responsibility for navigation. This will require a new, unprecedented contractual template to be developed.

Offering a technology-reliant navigational service would, in effect, entail that the technology provider assumes full operational responsibility for the ship. The crucial questions relate to the terms on which the shipowners would be willing to let technologies determine what happens on the ship. Here, everything remains speculative. It seems conceivable that the manufacturers of autonomy equipment would have to provide usability and performance guarantees or otherwise tie their compensation to technology performance. Similarly, they could have to assume liability for third party losses and damage to or loss of the shipowner's ship. Were this to happen, a significant change in operational responsibility patterns would take place with direct implications on, in particular, the insurance arrangements underlying marine operations.

4.5.3.4 The future of marine insurance

Here an excursus into marine insurance patterns and their likely future is in order. Three main insurance policy types transmit seafaring risks to insurers. First, most jurisdictions require that shipowners procure protection and indemnity (P&I) policies to guarantee that third party losses caused by marine accidents are compensated to aggrieved parties. Second, hull and machinery or hull policies secure the shipowners against the loss of and damage to the ship. Cargo insurance, third, ensures that cargo owners do not suffer losses due to accidents, as carriers have limited liability for cargo damage.

As the policies are in widespread use, the three policy types effectively transfer most maritime risks to insurers, leaving ship and cargo owners primarily exposed to deductible amounts and future premium increases if and when accidents take place.

> Most maritime accident risks are born by insurers.

The report argues that MASS introduction may prove disruptive to the insurance markets and transform marine insurance provision on three axes. First, P&I and hull insurance markets, as briefly touched upon above, currently gravitate around the shipowners. Shipowners procure and pay for the cover, and their actions and choices primarily affect the ship risk profiles. Shipowners man, maintain and repair the ships, and, albeit often indirectly, control ship design choices.

With the introduction of MASS technologies, the risk picture changes fundamentally. Instead of the crew, equipment and code will be the primary sources of navigational risk. Maintenance patterns will similarly change, moving the focus from continuous maintenance by the crews to manufacturer-determined work schedules and work done by external maintenance providers. The shipowners and yards could even see their control over ship technical composition disappear. The autonomy equipment manufacturers could bring in addition the equipment their own "makers lists" and determine the components that are to be included in the ships.

> MASSs may disrupt established maritime risk patterns.

The transformations could shift the insurers' focus away from the shipowners and towards the autonomy equipment manufacturers as the primary parties affecting risk creation on ships. The implications are clearest in relation to navigational risk. In AO-MASSs, navigational risk is a function of technology performance, forcing insurers to attempt to manage the technological risks. In RO-MASSs, navigational risk depends, in addition, on the SCC operators. Consequently, the price and availability of cover could, in the future, depend on what equipment is used on the ships and who provides the operational services. In such a world, one could, perhaps, see a future where each of the autonomy equipment manufacturers has its own partner insurer who knows the technologies, is involved in both development and testing processing, and, finally, insures all ships that carry the manufacturer's equipment.

> MASS navigational risk is technological risk and managing it will require new approaches.

Simultaneously, it seems that neither the current hull market, with its countless specialist underwriters, nor the P&I clubs are well positioned to face the technical challenges of managing the risks and pricing MASS cover. Risk management and pricing requires extensive technological expertise, possibly accumulated while underwriting firms from multiple technology industries.

The systemic character of MASS risks is likely to compound the effects outlined above. While MASS technologies are likely to make marine traffic safer on the average, the inevitable reliance on a limited number of software instances will expose the MASS insurance market to systemic low probability and high impact software events, such as concerted, fleet-wide cyber events.

To illustrate, imagine that in ten years a manufacturer is running a fleet of 200 AO-UCMASSs with a single insurer insuring the ships. The 200 ships are effectively clones of each other. They will "behave" identically under identical conditions. Further, imagine that a safety critical software bug slips into a software update despite the manufacturer's best efforts. The systemic nature of software risk entails that all ships running the new software update will be affected by the bug. If the bug causes an accident under conditions that are common in the fleet's operational domains, a significant number of the ships could suffer an adverse event. The probability of such a chain of events is very low, but the consequences possibly catastrophic with multiple adverse events following each other in close succession. In human systems, such loss cascades would be practically impossible as crew quality and responses are likely to vary and systemic "bugs" that affect multiple crews simultaneously should not exist. In MASS, this is a feasible, yet extreme risk scenario.

> MASS navigational risk is systemic and could expose insurers to high impact low frequency (HILF) events such as cyberattacks or safety-critical software bugs.

The example above illustrates that reliance on software in MASSs accentuates the significance of high impact, low frequency risks. Insurers will have to provide cover for low frequency software events that could trigger significant systemic loss cascades. While, for example, the P&I market currently has an exquisitely elaborate and deep reinsurance program in place, to guard against the extraordinarily large indemnity payments that may become payable in the worst case MSS accidents, the program seems built on the wish that such catastrophic accidents seldom take place. It seems inevitable that the market players will need new innovative contract structures to attract the capital needed to insure it against the extreme tail event scenarios possible in a future world where large scale MASS operations are a reality.

4.5.3.5 Ship construction contracts

4.5.3.5.1 The status quo

In addition to possibly causing repercussions in ship operations contract models and insurance provision, MASS introduction may discombobulate ship construction as well. Currently, in the ship construction phase, everything runs through the shipyard. While ships contain components from hundreds or thousands of manufacturers and potentially hundreds of individual contractors perform work on the ship when it is built, the shipyard is the hub for the work, as well as for most construction phase contracts. While the shipowner will ultimately get the ship, the shipyard runs the construction, entering into contracts with the equipment suppliers and contractors, while the future shipowner waits on the side-lines.

The standard ship construction process for the overwhelming majority of ships built (Stott2018) is summarized in Figure 12.

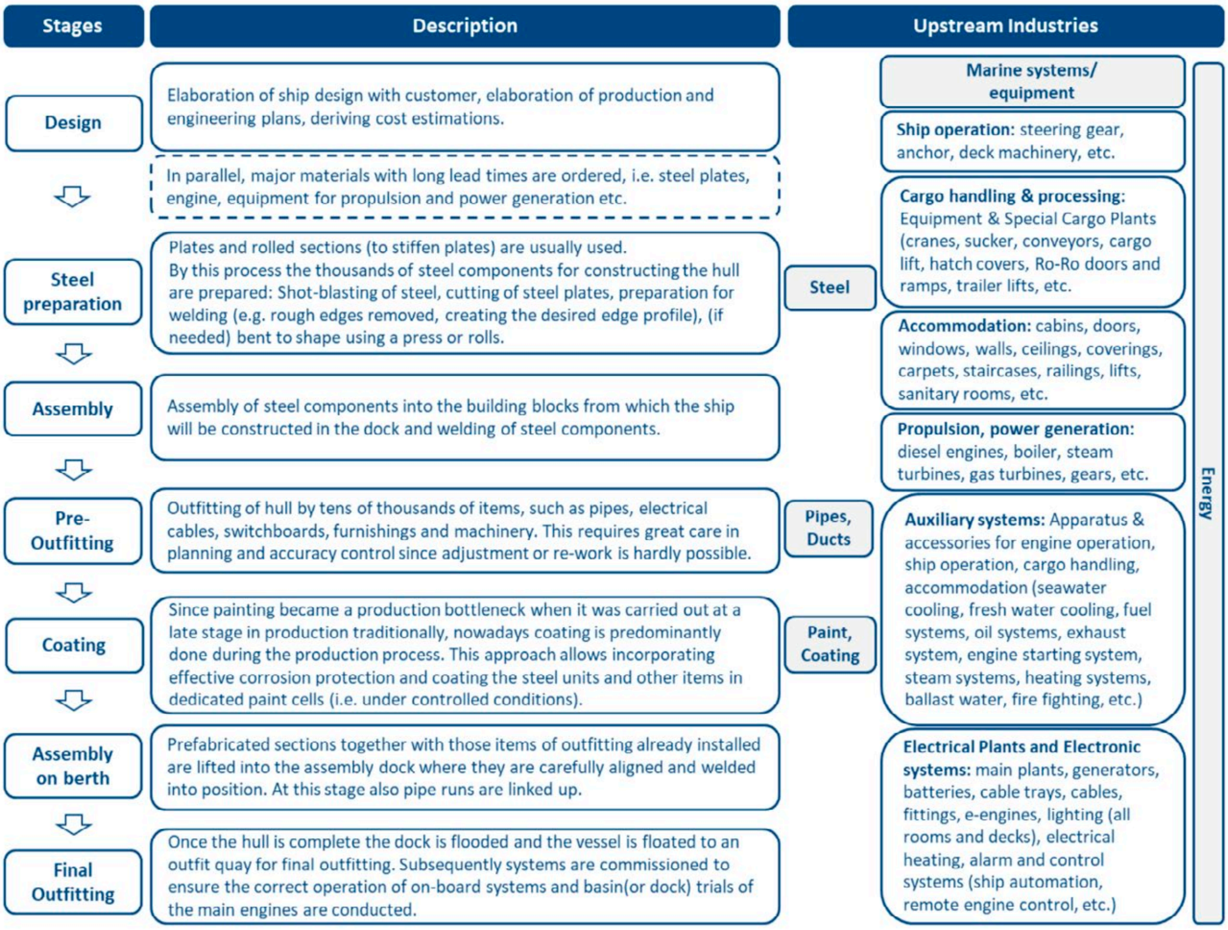

Figure 12. The shipbuilding process. (Source: Gourdon and Steidl 2019, 15).

The practices, of course, vary widely based on the type of ship to be constructed. Shipowners, in particular, are more involved in the construction of specialized ships and cruise ships. Crucially, the shipyard does not only act as the contractual hub but also as a liability stop for the shipbuilding phase. Acting as a liability stop is possible as contracts only confer rights on those who are privy to them. As the shipowner does not contract with the component manufacturers or the subcontractors doing the construction works, there is no contractual relationship between them and, consequently, no contractual rights. This entails that the owner has no direct claim right sounding in contract against the manufacturers, if, for example, a defective radar causes the ship to strand after acceptance. The owner can only make a claim against the shipyard.

Shipyards typically undertake to cure any defects that manifest within a year from delivery, after that the shipowners are on their own.

Second, even against the shipyard, the owner's contractual rights are typically severely limited. The yards regularly use contract forms that exclude liability for any defects discovered after acceptance of the vessel while issuing a limited guarantee. The yards undertake to rectify any defects during a guarantee period that typically has a one-year duration. The component manufacturers use similarly harsh terms to limit their liability towards the shipyard (Curtis 2012).

The end result is a liability landscape where the owner gets a ship and the shipyard commits to rectify the defects that went undiscovered prior to acceptance, but only during a short guarantee period, disclaiming all other liability. If a need for repairs arises, the yard is liable but typically pushes the costs contractually forward in the chain to its subcontractors or suppliers. The component manufacturers pick up the bill, if the components prove defective, while the contractors either redo their work or pay the costs, if work was defective. However, after the guarantee period, the owner has full operational responsibility for the ship.

4.5.3.5.2 MASS construction contracts

MASS introduction may put pressure on the current shipbuilding industry structures. Industry actors have indicated that transition to MASSs will require considerable adjustments to ship design and construction philosophies. The following discussion builds on the discussions with industry actors during the research conducted for the report.

To understand what may happen, it is important to characterise the present. Many shipyards function primarily as project management organizations. The shipyard's key competence is to, on the one hand, buy the materials and equipment at good prices and, on the other, coordinate steel and equipment installation works outsourced to contractor firms. While some significant innovations have taken place in recent decades in, for example, propulsion technology and, more recently, green tech and digitalization, the industry is characterised as relatively conservative. Its commitment to quality is often characterized as lacking in the face of cut-throat competition and overcapacity, in particular, compared to, for example, aircraft manufacturing.

> Shipbuilding is a conservative, highly competitive business with shipbuilders often struggling to maintain high quality standards.

MASS introduction would necessitate a wholesale reversal of many of these features. While the report has concentrated on ANSs as the core of the MASS technology palette, MASS introduction will likely require significant changes to many other core ship components as well. Engine and power plant maintenance intervals will have to become longer. With no crews present to perform maintenance work during the voyage, engines and power plants will have to remain functional for days if not weeks without intervention. The same is true of power transmission and propulsion equipment. With the inevitable transition to onshore maintenance, maintenance times will have to become shorter or equipment easily replaceable. Ship internal data transmission will force tight integration of electrical installation and ANS designs, as well as equipment choices. The intellectual frame for what ships are, will change from the steel in the hull to a high-tech vision of highly integrated, interlocking packages of technology that happen to be floating.

> Ships are built to be constantly maintained by crews.

These developments might lead to a situation where the shipyard changes from hub to an auxiliary service provider. As maker's lists proliferate and the choice of one particular equipment brings with it countless others, the yard's room for manoeuvre shrinks and it loses control over ship designs and procurement decisions. Here, the equipment manufacturers would likely take a more active role in designing the ships and specifying what equipment is to be used. Some actors see a future where autonomy equipment manufacturers partner up with other technological providers and, possibly, transportation end users to set up special purpose companies (SPC) that build the ship that the end user commits to use to transport their goods. These SPCs would, then, hire yards to do installation work, nothing else.

> MASS proliferation may induce changes to the current shipyard centric shipbuilding paradigm, accentuating the role technology suppliers p

Whether the vision is feasible or probable to come into fruition, remains unclear. Nevertheless, it would result in significant transformation of the contractual templates. Ships would no longer be sold as products, but would be constructed for the owner-SPC by contractor-yards that the SPC chooses and employs. The special purpose company would take care of financing the project during construction and enter into contracts with equipment suppliers. This approach could make sense if the revenue generated by the ship is highly dependent on how the technologies perform, and if the technology providers would want to capture the full value created by their offerings.

4.6. Data and MASS infrastructures

4.6.1 Data related issues

This chapter concludes with a discussion of data and infrastructure related issues. This section, first, discusses data in MASS contexts, outlining data protection and data sharing problems.

To set the scene, keep in mind that MASSs collect huge amounts of data. While communication and data sharing also take place in MSSs, ensuring expedient MASS traffic will increase the need for sharing data among traffic participants electronically and systematically. The report discusses data related concerns in two respects. First, data regulation may restrict MASS development and deployment. Second, safe and expedient MASS use may require that new categories of data are shared among traffic participants, authorities, and other stakeholders.

4.6.1.1 Data protection

Regulation has the potential to restrict what data can be collected, as well as how the data can be stored and processed in MASSs. Data regulation is highly stratified. While industrial and other non-personal data is subject to light or no regulation, personal data processing is strictly regulated in the EU. Here, it is important to note that MASSs will often trade in lightly populated areas, and, thus, are largely beyond the reach of personal data protection rules. Nevertheless, the ships may at times collect personal data in particular, as the EU GDPR definition of personal data is expansive. Consequently, data protection rules may constitute a legal hurdle to MASS introduction.

Personal data protection rules are relevant both in the MASS technology development and commercial trading phases. The applicable rules differ slightly in each phase.

The departure point is, however, common. In the EU, processing of personal data is only allowed if the data controller, a natural or legal person who determines the purposes and means of data processing, has a lawful basis for the processing. In the technology development phase, the party controlling the development is the data controller.
In commercial deployments, the amount of data controllers may increase. The party operating the MASS technologies is the primary data controller, although the shipowner, or the operating party, will likely be held a joint data controller.

The GDPR Article 6 lists multiple alternative bases to which data process appeal to justify data processing. Currently, the legal basis for data processing in MASSs is unclear.

Art 6(1)c could, potentially, provide a basis for processing data in deployment contexts, as the processing could be considered necessary for shipowners to comply with their legal obligations to navigate the ship safely.

Art 6(1)f and the legitimate interest basis for processing it contains could provide the lawful basis for data processing for both development and deployment purposes. Some Data Protection Authorities have indicated that they would hold algorithm development as a legitimate interest, provided that data is minimized and other data subject rights are secured. Similarly, MASS data controllers could argue that they have a legitimate interest in processing data while MASSs are trading. The legitimate interest test is a balancing test where the controller's interests are weighed against the interests or fundamental rights and freedoms of the data subject. To date, no authoritative body has weighed in on the issue. Even if the controller has a legal basis for the processing, the controller has to comply with the full roster of data subject rights.

Other privacy-related issues may also be relevant. As MASSs largely rely on visible light cameras for data collection, non-GDPR related complications may also arise. In Finland, the Penal Code 24:6 makes the unlawful watching and monitoring of a person in, for example, domestic premises punishable by a fine or imprisonment. A MASS camera system could conceivably watch or monitor domestic premises as the definition in Penal Code 24:11 is fairly extensive and covers "homes, holiday homes and other premises intended for residential use, such as hotel rooms, tents, mobile homes and vessels with sleeping capacity, as well as the stairwells and corridors of residential buildings and the private yards of the residents and their immediate outbuildings". Consequently, MASS operators could easily commit a crime if the cameras capture persons in their homes or yards. Observation can, however, be legal if the person who is observed has consented to observation or allowed in a statute. A statutory authorization is, therefore, likely required, in order to decriminalize MASS use in populated areas in Finland.

4.6.1.2 Mandating data sharing

Numerous rules already require ships to share information with authorities. Much of the information sharing is governed pursuant to The Convention on Facilitation of International Maritime Traffic (the FAL Convention). The Convention seeks to ensure that information requirements are globally uniform, in order to facilitate international maritime traffic by establishing limits on what documents and certificates IMO member states can require of a ship on arrival or departure. The Convention text primarily envisages that documents are carried in a physical form, but a guidance document has exhorted that all stakeholders should accept electronic certificates. For UC-MASSs, in particular, the use of electronic certificates should be expanded.

Further, the IMO e-Navigation strategy has emphasized the need to build comprehensive and uniform electronic infrastructures for maritime communications. Whereas the strategy seeks to streamline administrative operations, similar pressures to increase data sharing may arise from safety-related pursuits as well.

VTS providers will likely need information on MASS route plans. While some of the need can be met with FAL notifications, fulfilling VTS advice functions requires a two-way communication channel. In particular, UCMASSs may be problematic in this regard, as the ships will lack humans on the bridges and, thus, VTS communications to bridges must either be relayed to SCCs to be handled by human operators or somehow be handled by the ship autonomy systems.

The SCC option may be marred by connectivity issues. If VTS communications cannot be relayed to SCCs, the ship is effectively deaf and mute, without local natural language processing (NLP) capabilities. Even if relays work, standby crews on UMASSs and SCC staff of UCMASSs may need time to become fully informed of the ship's status and gain control of the situation.

Regulators could require that MASSs operating without active crews have NLP capabilities to allow for real-time communication with VTS providers. However, the report argues that regulators should preferably consider requiring that MASSs electronically communicate their large-scale voyage plans and tactical path plans to VTS providers with regular intervals. The communication interfaces and contents should be standardized. Opening a communication interface with VTS providers would allow the VTS providers to continue fulfilling their advice functions. Here, important data and cyber security concerns may arise.

As ports are seeking to streamline their operations, they have similar data transfer and sharing needs as well. For example, the port of Rotterdam is exploring methods for controlling and optimizing traffic within the port and making pier approaches and moorings safer by increasing the port authority's situational awareness and capability to choreograph ship movements.

Remote pilotage introduces another, although more extensive, set of requirements for standardized communication and data sharing interfaces. To remotely pilot a ship, the pilot needs a full situational awareness of the ship's position and environment. To facilitate pilotage of ships equipped with autonomous navigation systems from multiple manufacturers, the data interfaces need to be standardized.

Sharing route and path plans with VTS providers could provide a template for automated bridge-to-bridge communications. MASSs could be required to broadcast their strategic route plans and tactical path plans using, for example, an updated AIS+ protocol. This would allow MASSs to coordinate their movements and engage in collective route planning, and allow MSSs, if the AIS+ data is readable in ECDIS displays, to anticipate MASS actions. A similar approach could also be incorporated into MSS eNavigation requirements. The increased transparency and foreseeability of path plans would undoubtedly increase safety.

As alluded to above, sharing route and path plan data would require that regulators issue technical standards that articulate what data and what level of granularity is shared or broadcasted, as well as over what channels, in what format, at what intervals, and to whom. The high-level work on standards would likely fall within the ambit of the International Hydrographic Organization, with the general standardization bodies issuing the final detailed technical standards.

4.6.2 Infrastructures

Marine traffic is embedded in and made possible by a vast number of infrastructures. Safe navigation is, for example, facilitated by centuries of hydrographic research and the resultant charts. Fairways are often marked using beacons and seamarks, facilitating visual navigation. Traffic rules allow ships to anticipate action by other ships. Meteorological services provide seafarers up-to-date information on the conditions they may encounter during the voyage. Shore states provide ships vessel traffic services that maintain a "Recognized Maritime Picture" detailing the traffic on their territorial waters, coordinate traffic, and issue emergency orders. AIS provides location and movement data for nearby ships.

MASSs will share the existing maritime infrastructures with MSSs. While many existing infrastructures, such as hydrographic charts, are easily accommodated using readily available technologies, two sets of questions and challenges are likely to arise. Concerns can be raised over whether MASSs will be capable of operating within the existing infrastructure designed for human operated MSSs. Here, a number of potentially problematic infrastructures can be identified.

First, any infrastructures that rely on auditory natural language communication may offer considerable challenges for MASS developers. For example, real-time communications with VTS providers may be extremely difficult to technologically implement. Regulators should study what technologies could facilitate real-time communications with VTS providers.

Second, fairway markings, beacons, and other seamarks are currently designed for human operators. While these safety devices may play a secondary role in MASS navigational processes, they remain important fallback safety devices. However, as MASS sensory capabilities differ from those of human crew members, adding features designed to improve their observability could increase their usefulness for MASSs.

Regulators should study what additional features in fairway markings, beacons, and other seamarks could add to their value in MASS navigational processes. If MASSs fare bad in some infrastructures, regulators could explore building dedicated MASS infrastructures.

These MASS infrastructures could range from dedicated MASS fairways, other MASS only spaces, and data networks to devices that could convey information on MASS properties or MASS intentions to other maritime actors.

Dedicated MASS-only fairways or trade areas could disambiguate marine traffic conditions, lower the technological demands for MASS SA and navigational capabilities, and eliminate the problems that arise out of human unpredictability in mixed traffic conditions. Establishing protective no-go bubbles around MASSs would serve similar purposes.

Such solutions are, however, imperfect. Establishing a MASS-only space will not by itself guarantee that other ships do not enter the space. In addition, some seafarers may not be able to comply with such orders due to lacking knowledge or skills. Under these conditions, establishing a MASS-only space and allowing MASSs to trade in the space with no regard to other traffic, would allow MASSs to inflict physical harm to the non-compliant parties. This approach is not compatible with the current rules of marine traffic, which require that ships always take all available actions to prevent collisions and other accidents.

Regulators could explore establishing dedicated MASS-only fairways or trade areas, but the report recommends that the existence of MASS-only marine spaces should not be used as an excuse for certifying MASSs incapable of surviving in mixed traffic areas.

Maritime actors will likely need to be aware of which ships are operating under remote control or autonomously. Establishing a code for communicating the operational mode of a ship is, thus, a regulatory priority. Developing a technical solution that allows MASSs to broadcast their intentions to MSSs and other traffic participants is a similar issue. Both will require international cooperation under the auspices of IMO.

5 Executive Summary

5.1 Chapter 1: Report assignment, terminology, and scope

The Finnish Ministry of Transportation and Communications commissioned *Centrum Balticum* to draft a report to serve as background information in future work on the regulation of maritime autonomous surface ships.

According to the assignment set out in the call for tenders, the report was to deal with four high-level Assignment Questions:

1) What are the relationships between existing IMO, EU, and national regulatory frameworks in the context of MASS trials and pilot deployments inside test areas in the Baltic Sea?
2) What are the contents of existing IMO, EU, and national rules, and what is the rules' impact on possible MASS trials and pilot deployments?
3) How should the IMO, EU, and national regulation be changed to facilitate the trials and pilot deployment?
4) What kind of a regulatory framework would best support the accountability and liability of intelligent and automated maritime systems?

The report mission is to, ultimately, outline the contours of a solid regulatory framework for autonomous shipping operations, whatever their level and stage.

The framework should be able to deal with all these variations, and should not be limited to a specified level of manning or autonomy. As has been shown above, legal issues related to MASS do not arise only once the ship is fully autonomous or entirely unmanned. Even a partially unmanned ship, as well as a ship which is acting autonomously for only part of the time, needs a new regulatory framework, as they will be confronted with many of the same legal issues that apply to fully unmanned and/or autonomous ships.

The report, consequently, deals with a wide spectrum of topics.

In Chapter 2, the report discusses MASS technologies to set the scene. In Chapter 3, the report addresses Assignment Questions 1 to 3. In Chapter 4, the report addresses Assignment Question 4.

5.2 Chapter 2: MASS Technologies

The main computational tasks in autonomous navigation are maintaining situational awareness of the ego vessel and its surrounding environment, and navigational planning and control based on the situational awareness information. Situational awareness is composed using a variety of sensors, sensor-specific signal processing algorithms, and sensor fusion to combine information from multiple sources.

The main objectives for sensor fusion are to provide comprehensive and accurate information on object types and locations, and to enable redundancy to handle sensor failures or difficult operating conditions. In an autonomous system, it is necessary to assume that any sensor or subsystem may be affected by external conditions or may fail and cannot be immediately replaced. The system should still be able to operate safely despite such sensor limitations or failures. A relevant regulatory concern is to define requirements for autonomous vessels' operation in the presence of sensor failures, difficult environmental conditions, or malicious external influence such as sensor jamming and spoofing.

In situational awareness, the most significant applications for machine learning models are detecting objects from various sensor data and classifying these objects according to pre-trained categories. Such models provide both robustness for estimating object locations based on multiple sensor inputs and semantic information on objects such as types of vessels and aids to navigation. Automating visual watchkeeping as mandated by current maritime regulations requires the use of machine learning models, as no conventional rule-based algorithms provide comparable accuracy. In navigational planning, machine learning models can be used for example to predict the future trajectories of other vessels or control vessel manoeuvring systems in complex scenarios where it is not feasible to base route plans on explicit rules or conventional optimization algorithms. However, in navigational planning, ML models are not strictly required for any critical functionality, and they should be applied in combination with rule-based systems to ensure safe operation.

As machine learning models are applied in the considered systems in a similar way and for similar purposes as conventional signal processing algorithms, they do not present new ethical concerns per se. ML models may be necessary or useful components for automating tasks e.g. in watchkeeping or navigational planning currently required from human seafarers. However, by nature their correct performance cannot be fully guaranteed in all conditions and scenarios, and the difficulty of automating various navigation or watchkeeping tasks may vary greatly. It is therefore relevant for regulation concerning autonomous vessels to specify precisely what are the requirements for implementing navigational capabilities depending on ML models, and what are the technical performance criteria for such tasks and models.

Autonomous vessels require communication channels for multiple purposes such as monitoring the location, situational awareness, and route plans of the vessel in autonomous operation and offloading stored sensor data for algorithm development and data logging. A specific requirement pertinent also for autonomous vessel test areas is that they provide sufficient communication infrastructure for remote controlled operation. This can be enabled using existing cellular communication network technologies, but these need to guarantee sufficient bandwidth and availability in the operational area to ensure safety.

Machine learning models are not trained on board the vessel during operation, but on shore as part of normal system development. A characteristic of machine learning model development significant for regulation is that ML models cannot be comprehensively tested using conventional software validation and verification approaches. Validation of autonomous navigation systems containing ML components should be based on a combination of development process standards, statistical model, and algorithm testing using recorded sensor data sets, system simulations focusing on testing difficult navigation scenarios, and field trials.

Field tests are important for collecting sufficient data sets for evaluating practical sensor performance and subsequent ML model behaviours. A beneficial outcome from governmentally supported autonomous vessel testbeds and development projects could be the generation of common test data sets, either open or managed by regulators, which would be valuable in creating common performance requirements and standards for autonomous navigation systems.

5.3 Chapter 3: Regulatory challenges linked to MASS trial areas in the Baltic Sea

The existing legal challenges linked to operating MASS depend on four main issues:

1) The sea area concerned.
2) Applicable substantive law.
3) The level of autonomy of the operation.
4) Whether or not the operation is a trial.

The physical location of the MASS operation is important as it determines the level of state jurisdiction over the operation and what substantive laws apply. The main distinction is between ships in national trade and waters, and on international voyages. International operations require more attention to other states' interests under the law of the sea, but also involve an increased amount of applicable international rules and less opportunity for national exceptions or solutions.

MASS requirements will apply as additional to the requirements that would otherwise apply to the ship in question. Different requirements will therefore apply to MASS depending on whether they carry passengers or cargo, and on the category of ship and cargo involved. The relevant material standards are mainly to be found at either global (IMO) level or in the national rules of the flag states, which are heavily influenced by the IMO rules. EU maritime safety legislation plays a lesser role in this regard, but the Union's involvement is expected to increase when the legal obstacles to MASS are removed, and MASS become more common in the region.

Both international and national rules include certain obstacles to MASS operations at any level of autonomy. The obstacles are essentially the same at international and national levels: issues relating to the physical presence on board need to be resolved as well as clarifying the legality of technological lookout and processing of that information. Data-based decision-making in navigation would also need to be endorsed at international level before used outside trials. However, generally speaking, the direct conflicts are few, as most rules are made in the form of functions to be performed without specifying the methods. In addition, some of the rules provide important possibilities for flag state administrations to accept exemptions, equivalents or alternative design. While the legal conflicts are relatively few, a very broad range of IMO rules give rise to uncertainties as to how they are to be understood and interpreted in relation to MASS. The existing rules are simply based on the premise that there are people on board the ships and therefore many questions need to be clarified if that is not the case. This also applies to the safe manning process, which will be key in implementing MASS for individual ships.

The relative absence of direct legal conflict is significant also as it allows a broader range of tools to be used for addressing the problem. In particular, it opens up for IMO to make use of measures that are less heavy than convention amendments, such as joint interpretations, clarifying resolutions etc., to move the matter forward.

Different aspects of MASS give rise to different legal issues. For example, remote operation does not raise questions of principle relating to the exercise of 'good seamanship', as that seamanship may well be exercised from a different location than the ship itself. By contrast, remote operation raises a series of issues linked to the relationship between the MASS and its control centre, including communication standards and emergency procedures. Conversely, MASS that operate autonomously without any human involvement raise issues with respect to any rules that presume that there is a human in the decision-making loop, including COLREGS and various maritime liability rules.

A way of avoiding these kinds of legal objections would be to unman and automate the MASS to a certain degree, but not remove the entire crew from the ship. Even a single person with master's qualification on board could resolve a great number of the most difficult legal issues.

Another way of by-passing some of the legal obstacles is to operate the MASS as a trial, rather than as a permanent operation. During trials certain recent regulatory adjustments can be utilized, which provides more flexibility for the authorities involved. Challenges linked to different sea areas are analysed through four case studies, representing different types of MASS operations in the Baltic Sea. The case studies indicate that for national trials in Finland, the 2018 amendments to Act 1687/2009 provide a tool for overcoming the most serious obstacles. For international trials the IMO Interim Guidelines may have a similar effect, provided that the trials are positively received by all states involved in them. Practical considerations relating to infrastructure, traffic and general public support, may speak in favour of executing the trial in a pre-established dedicated trial area, but this would not in itself remove or alter any of the legal rights or obligations linked to MASS trials.

In the longer run, more solid regulatory regime is needed, and the key to achieving this lies in regulatory developments at IMO. It is proposed that a new Chapter in IMO's main safety convention, SOLAS, should be introduced. This chapter would be specifically dedicated to MASS and supplemented by underlying codes, and could provide a solid basis for that legal framework, which needs to accommodate a series of entirely new issues that have not been subject to regulation before. The relationship to other SOLAS provisions would be clarified in the new Chapter, while identified amendments of other conventions would have to take place separately. This would represent a 'quick' solution in that there would be no need for a separate ratification of the new Chapter, but the regulatory process is still likely to take at least a decade from the date where it is first agreed as a way ahead until it is amended and in force in the key IMO conventions.

5.4 Chapter 4: A future regulatory framework

The report Chapter 4 discusses the design parameters and constraints of the future regulatory framework suitable for governing commercial, large-scale MASS deployments in the medium-term future, once the initial testing and piloting phase has been completed. The report envisions that regulatory framework should primarily coalesce within the auspices of the IMO rule-making procedures, buttressed by some national legislative action.

To set the scene, the report commences with a discussion of the *ethical framework* in which MASSs should be positioned. As the core novelty of MASSs lies in their reliance on algorithmic decision-making, the report argues that the ethical framework is one of algorithmic ethics. The report then discusses algorithmic ethics and identifies safety as the priority ethical concern in MASSs, of course accompanied by other concerns. As navigation is the most important safety-critical function to undergo a radical transformation in transition to MASSs, the report, then, moves to identify and discuss the ethical flash points of technology-mediated navigation and the role that algorithmic transparency may play as an ethical regulation tool. The ethics part is rounded out by a short excursus into ethical design processes.

After establishing the ethical corner stones for MASS regulation, the report moves to discuss the future MASS regulatory framework. Regulatory standards ensuring that autonomous navigation systems (ANS) are capable of navigating the ships safely constitute the bedrock of the regulatory framework on which all MASS regulation will and must build. The report outlines the regulatory landscape, sets out the various regulatory options, and discusses their strength and weakness. Ultimately, the report arrives at a recommended structure for the future ANS regulatory framework.

The future autonomous navigation regulatory framework should be drafted by IMO and introduced as an amendment to SOLAS. The framework should focus on ensuring adequate navigational capability to ensure navigational safety. As an important part of the safety priority, the rules should ban MASSs that are "self-learning". Instead, all MASS ANS software components must be tested before approval and be stable during use. The rules should target situational awareness and navigational planning systems separately as the systems' technological compositions are different.

Regulators have three regulatory options available to regulate autonomous navigation systems. Regulators can engage in prescriptive technology regulation dictating what technologies should be used; regulators can set performance-based standards; or regulators can rely on transparency as a regulatory device. Regulators should put in place rules that combine performance-based rules and prescriptive technology regulation. The performance-based rules should put in place a hybrid simulation and real-world testing regime. The rules should mandate that an independent third develop, maintain, and administer the simulation tests. MASSs should be approved for use once the ANSs 1) have passed appropriate statistical validation procedures and simulation-based performance tests, have a sufficient track record of successful supervised performance, and 3) meet the prescriptive technical standards set for certification. After outlining the regulatory framework for autonomous navigation systems, the report discusses a selection of other regulatory issues.

The report, first, discusses how shore control centres on RO-MASSs should be regulated. SCC regulation should cover both the physical and technological composition of SCCs and the regulation of SCC staff. For the former, International Hydrographic Organization (IHO) standards for ECDIS could offer a template. For the latter, the rules should address how navigational work is organized in SCCs, how SCCs should be manned, and what training and qualification requirement should be for SCC staff. Second, the report explores how adequate connectivity can be ensured. Here, prescriptive technology regulation will likely be required. Third, the report discusses MASS should behave when experiencing connectivity breakdowns and ending up in too challenging operation domains. Here, the regulators should issue regulations that outline what strategies MASSs should pursue when they encounter an operational domain that is too challenging for their ANSs. Fourth, the report makes a short excursus into cyber security issues, arguing that the high risks involved MASS activities require strong cyber security regulation. Fifth, the report explores how communications with external parties, such as VTS operators and other ships should be organized.

After discussing the selected regulatory issues, the report moves to discuss *liability and accountability in MASS contexts*. The report outlines the current liability regime for MSS traffic and reflects on what changes MASS introduction may trigger. The discussion centres on non-contractual liability rules, including product liability, but also discusses the pressures that MASS introduction may impose on shipbuilding and ship operation contracts.

In particular, the report argues that existing third-party liability rules may create "liability gaps" as negligence-based liability standard will likely lose much of their capacity to legitimately allocate MASS accident costs. The report argues that regulators should consider introducing a strict liability regime to govern MASS operations where registered owners would be liable for all third-party losses caused by the MASSs they own. As industry actors use contracts to allocate liability amongst each other and the future MASS industry structures remain unclear, articulating optimal liability is not possible at the moment.

Finally, the report addresses *data and infrastructure* related issues. The report, first, argues that data regulation may introduce important constraint that seem likely to add uncertainty to MASS development and deployments. Second, the report also argues that regulators should explore regulatory options to encourage and mandate data sharing. Third, the report argues that the regulatory framework may have to be buttressed by an infrastructure layer that attempts to make the MASS operational environment MASS friendly. The infrastructure measures could range from expanding the scope of the obligation to carry AIS transponders, radar reflectors, and introducing a new obligation to carry MASS compatible communication equipment to reforming VTS services provision.

6 Johdon tiivistelmä

6.1 Pääjakso 1: Raportin toimeksianto, terminologia ja rajaus

Suomen liikenne- ja viestintäministeriö antoi *Centrum Balticum* -säätiölle tehtäväksi laatia raportin, joka toimii taustatietona tulevaisuuden autonomisten laivojen (Maritime Autonomous Surface Ship, MASS) sääntelyssä.

Tarjouspyynnössä esitetyn toimeksiannon mukaan raportin tulee käsitellä neljä teemaa:

1) Mikä on voimassa olevien eri sääntelykehysten (IMOn, EU:n ja kansallinen sääntely) välinen suhde Itämeren eri alueilla mahdollisesti suoritetuissa erilaisissa kokeiluissa ja pilotoinneissa?
2) Mikä on voimassa olevan sääntelyn (IMOn, EU:n ja kansallinen sääntelyä) nykytila? Miten voimassa oleva sääntely mahdollistaa tai estää Itämeren koealueen rakentamista ja hyödyntämistä sekä siellä suoritettavia kokeiluja ja pilotointeja eri Itämeren alueilla, toimintaympäristöissä sekä automaatiotasoilla?
3) Miten sääntelyä (IMOn, EU:n ja kansallinen sääntelyä) pitäisi muuttaa, jotta kokeilut mahdollistuisivat? Millaisia vaikutuksia Itämeren koealueesta voisi olla sääntelylle? Minkälainen automatisaation tasomäärittely olisi tarkoituksenmukaisin Itämeren koealueella suoritettavia kokeiluja ja pilotointeja varten?
4) Millainen viitekehys tukisi parhaiten merenkulun älykkäiden ja automatisoitujen järjestelmien ml. algoritmien läpinäkyvyyttä ja vastuita (accountability, liability)?

Raportin ensisijaisena tehtävänä on hahmotella muotoja toimivalle sääntelykehykselle, jolla voitaisiin hallita autonomista meriliikennettä, autonomisuuden tasosta ja vaiheesta riippumatta.

Kehyksen tulisi pystyä käsittelemään kaikkia autonomisen meriliikenteen variaatioita, rajoittumatta tiettyyn miehityksen tai autonomian tasoon. Kuten edellä on osoitettu, autonomiseen meriliikenteeseen liittyviä oikeudellisia kysymyksiä ei esiinny ainoastaan aluksilla, jotka ovat täysin itsenäisiä tai kokonaan miehittämättömiä. Myös osittain miehittämättömät alukset sekä vain osan ajasta itsenäisesti toimivat alukset tarvitsevat uuden sääntelykehyksen, sillä ne tulevat myös kohtaamaan monia niistä oikeudellisista kysymyksistä, jotka tulevat koskemaan miehittämättömiä ja/tai itsenäisiä aluksia.

Näin ollen raportti käsittelee laajaa kirjoa aiheita.

Pääjakso 2 johdattaa lukijan MASS-teknologioihin. Pääjaksossa 3 käsitellään kysymyksiä 1-3, ja pääjaksossa 4 käsitellään kysymystä 4.

6.2 Pääjakso 2: MASS-teknologiat

Tärkeimmät laskennalliset tehtävät autonomisessa navigoinnissa ovat aluksen ja sitä ympäröivän ympäristön tilannetietoisuuden ylläpito sekä tilannetietoisuuteen perustuva navigointisuunnittelu ja -hallinta. Tilannetietoisuus saavutetaan käyttämällä useita antureita ja anturikohtaisia signaalinkäsittelyalgoritmeja sekä yhdistämällä tietoja useista lähteistä Anturifuusion päätavoitteena on tarjota kattavaa ja tarkkaa tietoa ulkoisten kohteiden tyypeistä ja sijainneista, sekä luoda anturivikojen tai vaikeiden käyttöolosuhteiden hallinnan mahdollistava redundanssi. On välttämätöntä olettaa, että ulkoiset olosuhteet voivat vaikuttaa mihin tahansa autonomisen järjestelmän anturiin tai osajärjestelmään ja että niissä voi yllättäen tapahtua jokin vika, jota ei ole välittömästi mahdollista korjata. Järjestelmän tulee kuitenkin pystyä toimimaan turvallisesti antureiden mahdollisista rajoituksista tai vioista huolimatta. Oleellisena sääntelytarpeena on määritellä vaatimukset autonomisten alusten toiminnalle tilanteissa, joihin liittyy anturivikoja, vaikeita ympäristöolosuhteita tai haitallisia ulkoisia vaikutuksia, kuten antureiden häirintää.

Tilannetietoisuuden saavuttamisessa koneoppimismallien tärkeimmät käyttötarkoitukset ovat esineiden havaitseminen erilaisista anturitiedoista ja näiden luokittelu malleille ennalta opetettujen luokkien mukaan. Tällaiset mallit tarjoavat sekä vakautta kohteen sijaintien arvioimiseen useiden anturisyöttöjen perusteella, että semanttista tietoa esineistä, kuten erilaisista aluksista ja merimerkeistä. Visuaalisen vahdinpitotoiminnan automatisointi nykyisen merenkulkumääräyksen mukaan edellyttää koneoppimismallien käyttöä, koska mikään tavanomainen sääntöihin perustuva algoritmi ei tarjoa vertailukelpoista tarkkuutta. Navigointisuunnittelussa koneoppimismalleja voidaan käyttää esimerkiksi ennustamaan muiden alusten tulevia reittejä tai ohjaamaan aluksen ohjailujärjestelmiä monimutkaisissa tilanteissa, joissa reittisuunnitelmia ei ole mahdollista perustaa nimenomaisiin sääntöihin tai tavanomaisiin optimointialgoritmeihin. Mikään kriittinen navigointisuunnittelun toiminto ei kuitenkaan ehdottomasti vaadi koneoppimismalleja, joten niitä tulisi käyttää yhdessä sääntöihin perustuvien järjestelmien kanssa turvallisen toiminnan varmistamiseksi.

Koneoppimismallit eivät sinänsä aiheuta uusia eettisiä huolenaiheita, sillä niitä sovelletaan tarkastelluissa järjestelmissä samalla tavalla ja samankaltaisiin tarkoituksiin kuin tavanomaisiakin signaalinkäsittelyalgoritmeja. Koneoppimismallit voivat olla välttämättömiä tai hyödyllisiä komponentteja sellaisten tehtävien automatisoinnissa, joiden suorittaminen tänä päivänä vaati ihmisen toimintaa. Tällaisia tehtäviä ovat mm. vahdinpito ja navigointisuunnittelu. Luonnollisesti koneoppimismallien asianmukaista suorituskykyä ei kuitenkaan voida täysin taata kaikissa olosuhteissa ja tilanteissa, ja erilaisten navigointi- tai vahdinpitotehtävien automatisoinnin aiheuttamat vaikeudet voivat vaihdella suuresti. Siksi on tärkeää, että autonomisten alusten sääntely täsmentää tarkalleen, mitkä ovat koneoppimismallikohtaiset vaatimukset navigointikyvyn toteuttamiseksi, ja mitkä ovat tällaisten tehtävien ja mallien tekniset suorituskriteerit.

Autonomiset alukset vaativat viestintäkanavia useisiin tarkoituksiin, kuten aluksen sijainnin, tilannetietoisuuden ja reittisuunnitelmien tarkkailuun autonomisessa tilassa, sekä tallennettujen anturitietojen keräämiseen aluksilta algoritmien kehittämistä ja tiedonkeruuta varten. Erityinen vaatimus, joka koskee myös autonomisten alusten testialueita, on että käyttöalueet tarjoavat riittävän viestintäinfrastruktuurin kauko-ohjattua toimintaa varten. Tämä voidaan mahdollistaa jo olemassa olevien matkapuhelinverkkotekniikoiden avulla, edellyttäen, että ne voivat taata riittävän kaistanleveyden ja saatavuuden käyttöalueella, turvallisuuden varmistamiseksi.

Koneoppimismalleja ei kouluteta toiminnassa olevalla aluksella, vaan maissa normaalin järjestelmän kehittämisen yhteydessä. Sääntelyn kannalta merkittävä koneoppimismallien kehittämisen ominaispiirre on se, että koneoppimismalleja ei voida testata kattavasti käyttämällä tavanomaisia ohjelmistojen kelpoistamis- ja todentamismenetelmiä. Koneoppimiskomponentteja sisältävien autonomisten navigointijärjestelmien toiminnan varmistamisen tulisi perustua kehitysprosessistandardien, tilastollisten mallien ja algoritmien testiyhdistelmään, jossa käytetään tallennettuja anturitietoja, vaikeiden navigointiskenaarioiden testaamiseen keskittyviä järjestelmäsimulaatioita sekä kenttäkokeita.

Kenttäkokeet ovat tärkeitä riittävien aineistojen keräämisessä antureiden ja koneoppimismallien suorituskyvyn arviointiin. Mahdollinen hyödyllinen lopputulos valtion tukemista autonomisten alusten testeistä ja kehitysprojekteista olisi keskitetysti järjestelmien testaamiseen hyödynnettävissä olevien tietoaineistojen kerääminen. Nämä voisivat olla joko avoimia tai viranomaisten hallinnassa, ja olisivat hyödyllisiä yhteisten suorituskykyvaatimusten ja standardien kehittämisessä autonomisille navigointijärjestelmille.

6.3 Pääjakso 3: Itämeren MASS-koealueisiin liittyvät sääntelyn haasteet

Nykyiset MASS-toimintaan liittyvät oikeudelliset haasteet riippuvat neljästä pääkysymyksestä:

1) Kyseessä oleva merialue.
2) Sovellettava oikeus.
3) Autonomian taso.
4) Onko kyseessä kokeilu vai ei.

MASS-toiminnan fyysinen sijainti on tärkeä, koska se määrittää valtion merioikeudellisen toimivallan ja sovellettavat substanssilait. Tärkein ero on kansallisen ja kansainvälisen liikenteen välillä. Kansainväliset toiminnot vaativat suuremman huomion kiinnittämistä muiden valtioiden oikeuksiin, mutta niihin pätee myös suurempi määrä kansainvälisiä sääntöjä ja vähemmän mahdollisuuksia kansallisiin poikkeuksiin tai erityisratkaisuihin.

MASS-vaatimuksia sovelletaan niiden vaatimusten lisäksi, joita muuten sovellettaisiin kyseiseen alukseen. Siksi MASS:iin sovelletaan erilaisia vaatimuksia siitä riippuen, kuljettavatko ne matkustajia vai rahtia, sekä minkälaisesta laivasta ja rahdista on kyse. Asiaankuuluvat säännöt löytyvät pääasiassa joko kansainväliseltä merenkulkujärjestöltä (IMO) tai lippuvaltion kansallisista säännöistä, jotka pitkälti perustuvat IMOn sääntöihin. EU:n meriturvallisuuslainsäädännöllä on vähemmän merkitystä tässä suhteessa, mutta unionin osallistumisen odotetaan lisääntyvän, kun MASS:in oikeudelliset esteet poistetaan IMOn tasolla, ja MASS yleistyy.

Sekä kansainväliset että kansalliset säännöt sisältävät joitakin oikeudellisia esteitä MASS-toiminnalle kaikilla autonomian tasoilla. Esteet ovat pohjimmiltaan samat kansainvälisellä ja kansallisella tasolla: fyysiseen läsnäoloon aluksella liittyvät kysymykset on ratkaistava, ja tekniseen tähystykseen liittyvät oikeudelliset kysymykset selvitettävä.

Autonominen navigointipäätöksenteko olisi myös hyväksyttävä kansainvälisellä tasolla ennen kuin sitä voidaan ottaa käyttöön kokeiden ulkopuolella. Suorat ristiriidat ovat kuitenkin yleisesti ottaen vähäisiä, koska useimmat säännöt ovat laadittu toimintovaatimusten muodossa, määrittelemättä menetelmiä joilla ne saavutetaan. Lisäksi jotkin säännöt tarjoavat lippuvaltion hallinnoille tärkeitä mahdollisuuksia poikkeuksiin, tai vastaavien tai vaihtoehtoisten mallien hyväksymiseen.

Vaikka suoranaisia oikeudellisia konflikteja on suhteellisen vähän, IMOn sääntöjen suuri määrä aiheuttaa epävarmuutta siitä, miten niitä on tulkittava suhteessa MASS:iin. Nykyiset säännöt perustuvat oletukseen, että aluksilla on ihmisiä, ja siksi monia kysymyksiä on selvennettävä, jos näin ei ole. Tämä koskee myös miehitysprosessia, joka on avain MASS:in toteuttamisessa yksittäisille aluksille.

Suorien oikeudellisten konfliktien suhteellinen puuttuminen antaa myös mahdollisuuden käyttää laajempaa työkaluvalikoimaa ongelman ratkaisemiseen. Erityisesti se antaa IMOlle mahdollisuuden käyttää toimenpiteitä, jotka ovat vähemmän raskaita kuin yleissopimuksen muutokset, kuten esim. yhteisiä tulkintoja, selventäviä päätöslauselmia jne.

MASS:in eri aspektit herättävät erilaisia oikeudellisia kysymyksiä. Esimerkiksi aluksen etäohjaus ei nosta periaatteellisia kysymyksiä, "hyvän merimiestavan" harjoittamiseen, koska kyseistä tapaa voidaan hyvinkin harjoittaa eri sijainnista kuin aluksesta itsestään. Sitä vastoin etäkäyttö herättää sarjan kysymyksiä, jotka liittyvät MASS:in ja sen ohjauskeskuksen väliseen suhteeseen, mukaan lukien tiedonsiirtostandardit ja hätätoimenpiteet. Vastaavasti täysin autonominen MASS, joka toimii itsenäisesti ilman ihmisen osallistumista, herättää kysymyksiä säännöistä, joissa oletetaan olevan ihminen päätöksentekoketjussa, mukaan lukien COLREGs ja erilaiset vastuun säännöt.

Yksi tapa välttää tällaisia oikeudellisia haasteita olisi MASS:in automatisointi tietyssä määrin, poistamatta koko miehistöä alukselta. Jopa yksi henkilö laivalla, jolla on aluksen päällikön pätevyys, ratkaisisi monta haasteellisinta oikeudellista ongelmaa.

Toinen tapa sivuuttaa joitain oikeudellisia esteitä on operoida MASS:ia kokeiluna eikä pysyvänä operaationa. Kokeiden aikana voidaan hyödyntää tiettyjä viimeaikaisia sääntelymuutoksia, mikä lisää joustavuutta asianomaisille viranomaisille.

Eri merialueisiin liittyvät haasteet analysoidaan neljällä tapaustutkimuksella, jotka edustavat erityyppisiä MASS-operaatioita Itämerellä. Tapaustutkimukset osoittavat, että Suomen kansallisten kokeiden osalta vuoden 2018 muutokset laivaväkilakiin (1687/2009) tarjoavat työkalun vakavimpien esteiden voittamiseksi.

Kansainvälisten kokeiden osalta IMOn väliaikaisilla suuntaviivoilla voi olla samanlainen vaikutus, edellyttäen että kaikki niihin osallistuvat valtiot suhtautuvat kokeiluihin myönteisesti. Ennalta määritetty koealue ei sinänsä poista tai muuta MASS-kokeisiin liittyviä oikeuksia tai velvoitteita, mutta kokeilun siirtäminen sellaiselle alueelle voisi tuoda muita etuja, esimerkiksi liittyen infrastruktuuriin, muun liikenteen tiedottamiseen ja julkiseen tukeen.

Pidemmällä tähtäimellä tarvitaan vankempaa sääntelyjärjestelmää, ja avain tämän saavuttamiseen on IMOn sääntelykehityksessä. Raportti ehdottaa, että IMOn pääturvallisuusyleissopimukseen, SOLASiin, lisätään uusi luku. Tämä luku olisi erityisesti omistettu MASS:ille ja sitä täydennettäisiin taustalla olevilla koodeilla, ja se voisi tarjota vankan perustan tälle oikeudelliselle kehykselle, jonka on otettava huomioon myös kysymyksiä, joita ei ole aiemmin säännelty. Suhde muihin SOLAS-määräyksiin selvennettäisiin uudessa luvussa, kun taas muiden yleissopimusten yksilöityjen muutosten olisi tapahduttava erikseen. Tämä olisi ”nopea” ratkaisu, koska uutta lukua ei tarvitsisi erikseen ratifioida, mutta sääntelyprosessi todennäköisesti kestää silti vähintään vuosikymmenen siitä päivästä, jolloin toimintamallista sovitaan, kunnes muutokset ovat astuneet voimaan IMOn tärkeimmissä yleissopimuksissa.

6.4 Pääjakso 4: Tulevaisuuden sääntelykehys

Raportin pääjaksossa 4 käsitellään tulevan sääntelykehyksen suunnitteluparametreja ja rajoitteita. Tarkoituksena on tuottaa käsitys, millaisella sääntelykehyksellä voitaisiin hallita kaupallista, laajamittaista MASS-toimintaa, kun testaus- ja pilotointivaihe on saatu päätökseen. Raportin mukaan sääntelykehystä tulisi ensisijaisesti kehittää IMOssa, mutta sitä voidaan tukea kansallisilla täsmälainsäädäntötoimilla.

Raportissa käsitellään ensin eettistä viitekehystä, joissa MASS:ien kehittämistä tulisi hahmottaa. Koska MASS:ien keskeisenä uutena ominaisuutena on niiden riippuvuus algoritmisesta päätöksenteosta, raportissa esitetään, että keskeistä on keskittyä algoritmien etiikkaan. Raportissa käsitellään algoritmietiikkaa ja tunnistetaan, että turvallisuus on ensisijainen eettinen huolenaihe MASS:eissa. Koska navigointi on turvallisuuden kannalta merkittävin toiminto ja se muuttuu radikaalisti siirryttäessä MASS:eihin, raportissa keskitytään tämän jälkeen tunnistamaan ja keskustelemaan teknologiavälitteisen navigoinnin eettisistä polttopisteistä ja algoritmisen läpinäkyvyyden roolista eettisenä säätötyökalu. Eettinen osa päätetään lyhyellä katsannolla eettisiin suunnitteluprosesseihin.

MASS-sääntelyn eettisten kulmakivien vahvistamisen jälkeen raportissa siirrytään käsittelemään tulevaa MASS-sääntelykehystä. Keskeiseksi teemaksi nousee, miten sääntelyllä pystytään varmistamaan, että autonomiset navigointijärjestelmät (ANS) kykenevät navigoimaan aluksia turvallisesti. Raportissa hahmotellaan sääntely-ympäristöä, kartoitetaan erilaisia sääntelyvaihtoehtoja ja käsitellään niiden vahvuuksia sekä heikkouksia.

Raportissa esitetään seuraavat huomiot tulevasta ANS-sääntelykehyksestä. Ensimmäiseksi, sääntelykehys tulisi laatia IMOn piirissä ja se tulisi toteuttaa muutoksena SOLAS:iin. Toiseksi, sääntelyssä tulisi keskittyä ensi sijassa varmistamaan, että laivoilla on riittävän navigointikyky, jotta merenkulku olisi turvallista. Sääntöjen tulisi kieltää

”itseoppivat” navigointijärjestelmät, jotka muuttuvat tuotantokäytössä. Kaikki laivojen navigaatiojärjestelmien ohjelmistokomponentit olisi sen sijaan testattava ennen hyväksyntää ja niiden on oltava vakaita käytön aikana.

Tilannetieto- ja navigointisuunnittelujärjestelmille tulisi laatia erilliset säännöt, sillä järjestelmien tekninen rakenne on erilainen.

Sääntelyvaihtoehtoja on kolme: voidaan asettaa teknologiastandardeja, jotka määräävät, mitä teknologioita tulee käyttää laivoissa, suorituskykyvaatimuksia tai edellyttää, että valmistajat julkistavat järjestelmäkuvaukset. Raportissa esitetään, että sääntelyjärjestelmässä tulisi koostua suorituskykyvaatimuksista ja teknologista vaatimuksista. Suorituskykyvaatimukset olisi toteutettava yhdistelmänä simulaatioperusteista ja kenttäkokeille perustaa testausta ja validointia. Riippumattoman kolmannen tahon tulisi hallinnoida simulaatioperusteista validointijärjestelmää. Autonominen laiva tulisi voida ottaa kaupalliseen käyttöön vasta, kun sen navigaatiojärjestelmä on 1) läpäissyt asianmukaisen simulaatioperusteisen validointimenettelyn, 2) järjestelmästä on kertynyt turvallisuusnäyttöä ja 3) järjestelmä täyttää asetetut teknologiavaatimukset.

Autonomisten navigaatiojärjestelmien viitekehyksen tarkastelun jälkeen raportissa käsitellään eräitä muita sääntelyteemoja.

Ensin käsitellään etäoperointikeskuksiin liittyviä kysymyksiä: sitä, minkälaisia fyysisiä teknisiä vaatimuksia etäoperointikeskuksille olisi asetettava ja miten keskusten henkilökuntaa olisi säänneltävä. Ensin mainitussa tapauksessa International Hydrographic Organization IHOn ECDIS-standardit voivat tarjota mallin sääntelylle. Jälkimmäisessä tapauksessa olisi säänneltävä sitä, miten työ järjestetään keskuksissa, minkälaisia miehitysvaatimuksia asetetaan ja minkälaisia kelpoisuusvaatimuksia henkilökunnalle tulisi asettaa. Toiseksi käsitellään tietoliikenneyhteyksiä. Niiden osalta sitova teknologiasääntely vaikuttaa järkevimmältä vaihtoehdolta. Kolmanneksi hahmotellaan, miten yhteyskatkoksiin ja muihin häiriötilanteisiin pitäisi varautua. Suositus on, että sääntelyllä varmistetaan, että laivoilla on tarvittavat algoritmit häiriötilanteista selviämiseen. Neljänneksi käsitellään kyberturvallisuutta. Viidenneksi raportissa hahmotellaan kommunikaatiosääntelyä.

Seuraavaksi käsitellään autonomisten laivojen vastuukysymyksiä. Raportissa hahmotellaan nykyistä vastuusääntöjärjestelmää ja pohditaan, millaisia muutoksia autonomiset laivat voivat niissä aiheuttaa. Raportissa keskitytään sopimuksenulkoiseen vastuuseen, mukaan lukien tuotevastuu, mutta sivutaan myös paineita, joita autonomisista laivoista saattaa aiheutua laivanrakennus- ja laivojen operointisopimuksille.

Tarkastelussa havaitaan, että autonomisuuden myötä voi syntyä vastuuaukkoja, koska tuottamus- ja syyllisyysperusteisten vastuumuotojen rakenne on autonomiakonteksteissa ongelmallinen. Autonomiakonteksteissa kun on vaikea löytää syyllisiä. Raportissa suositaan, että lainsäätäjä harkitsisi, että autonomisten laivojen omistajille säädettäisiin yleinen ankara vastuu laivojen aiheuttamista vahingoista. Ankara vastuu tarjoaisi oikeudenmukaisen, vakaan ja yksinkertaisen pohjan, jonka varaan osapuolet voisivat sitten vastuusuhteensa järjestää sopimuksin.

Viimeisessä osiossa tarkastellaan dataan ja infrastruktuureihin liittyviä kysymyksiä. Keskeinen huomio on, että datasääntely voi rajoittaa merkittävästi autonomisten laivojen kehitystyötä ja kaupallista käyttöä. Lisäksi olisi syytä selvittää, voitaisiinko datan jakamiskäytäntöjä kehittää. Autonomisen merenkulun infrastruktuuria on myös kehitettävä siten, että se helpottaisi laivojen operointia. Esimerkiksi pakko käyttää AIS-lähettimiä, tutkaheijastinten käytön lisääminen ja VTS-toimintojen uudelleenjärjestely voisivat olla mahdollisia infrastruktuurikehityshankkeita.

7 Glossary

A* algorithm

An algorithm designed for path planning in mobile robotics.

Algorithm

A set of rules that must be followed when solving a particular problem.

Acoustic camera

An array consisting of several microphones enabling estimating the direction of arriving sounds.

Automatic identification system (AIS)

A VHF-based system for self-reporting vessel location and metadata, mandatory for commercial vessels.

AutoML

Methods for automating the typical steps in training machine learning models.

Autonomous navigation system

A system for automated navigation planning and control in autonomous ships.

Artificial neural networks (ANN)

The dominant paradigm of state-of-the-art machine learning models. Networks of computing nodes joined by weighted connections, which mimic the functionality of biological neural networks.

Artificial potential field (APF)

A simulated potential field, where attractive and repulsive forces affect an object depending on its location.

Bandwidth

The maximum data transfer capacity of a communication channel.

Berthing

Mooring a ship in its allotted place.

Black box model

A model defining the functional relationships between system inputs and outputs, where typically the model parameters are not based on explicit rules.

BeiDou Navigation Satellite System (BDS)

A global navigation satellite system of Chinese origin.

Catastrophic interference

The tendency of an artificial neural network to forget previously learned information when trained on new data.

Closest point of approach (CPA)

The estimated point where the distance between passing vessels reaches its minimum value.

COLREGs

Convention on the International Regulations for Preventing Collisions at Sea.

Computational geometry methods

Algorithms which can be stated in terms of geometry.

Computational complexity

The amount of computational resources or operations needed to perform a computation.

Computational optimization

Reducing the computational complexity of a computing task.

Computer vision

Algorithms designed for automating visual perception tasks for digital images.

Control system

A system which manages the behaviour of other devices or systems typically in a feedback loop.

Cost function

The target function to be minimized in mathematical optimization.

Crowdsourcing

The activity of getting information or help for a project or a task from many people, typically using the internet.

Data annotation

Categorization or labelling data with metadata for machine learning applications.

Data logging

Collecting and storing data over time to analyse or inspect a system's operation.

Data rate

The rate at which a data source produces data, measured for example in bytes per second.

Deep learning

Machine learning methods based on large artificial neural networks.

Deep neural network

An artificial neural network with many layers.

Ego vessel

The vessel with respect to which surrounding objects are observed.

False negative

In object detection, failure to detect an object from the set of target classes.

False positive

In object detection, reporting detection of an object when one is not present.

Galileo

A global navigation satellite system of European origin.

Globalnaja navigatsionnaja sputnikovaja sistema (GLONASS)

A global navigation satellite system of Russian origin.

Global navigation satellite system (GNSS)

A general term for global navigation satellite systems.

Global positioning system (GPS)

A global navigation satellite system of US origin.

Global timing signal

A timing signal used as a common reference by multiple system components.

Heuristic optimization

Approximately solving an optimization problem when exact solutions are difficult to find.

Heuristics

A method of solving problems by finding practical ways of dealing with them, learning from experience.

Holdout set (test set)

A data set used to evaluate a machine learning model's final performance after training and validation.

Hydrodynamic forces

Forces arising from water particle velocity and acceleration.

Hyperparameter tuning

Choosing optimal hyperparameters (parameters used for controlling the learning process) for a learning algorithm.

Inertial measurement unit (IMU)

A device which uses sensors such as accelerometers, gyroscopes, and magnetometers to measure forces, angular rates, and orientations.

Inertial navigation system (INS)

A navigation device which uses inertial measurement units and computation to estimate its position, orientation, and velocity over time.

International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978

An international convention that sets minimum qualification standards for masters, officers and watch personnel on seagoing merchant ships and large yachts.

Intersection over Union (IoU)

A measure used for quantifying the accuracy of bounding boxes in object. detection

ISO

International Organization for Standardization.

Iterative process

Determining a result by repeating a cycle of operations.

Jamming

A form of electronical countermeasures designed to interfere with the operation of a sensor (typically radar).

Kalman filter

An algorithm commonly used in sensor fusion for combining noisy measurements from multiple sensors.

Lidar (light detection and ranging)

A sensor measuring distances by illuminating the target with laser light and measuring the reflections.

Long short-term memory (LSTM)

A neural network architecture with feedback connections commonly used for modelling sequential data.

Machine learning (ML) models

Computer algorithms that can learn and improve in a task based on experience without being explicitly programmed.

Maritime Autonomous Surface Ship (MASS)

A ship capable of and approved to operate under remote control or autonomously.

Maritime Surface Ship (MSS)

A non-MASS.

Multimodal sensor data

Data from multiple types of sensors.

Multichannel audio data

Audio data recorded simultaneously using multiple microphones.

Object classification

In computer vision, assigning a (typically single) label to an image.

Object detection

In computer vision, determining the locations, sizes, and classes of objects.

Operational domain

The environment in which the MASS operates.

Operational design domain

The environment in which the MASS was designed to operate: IEEE standard J3016: "… operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics."

Optimization algorithm

A procedure for finding the best solution from all feasible solutions.

Overfitting

Training a machine learning model to reproduce the training data very well, while failing to model other data not in the training set.

Pan-tilt-zoom (PTZ) cameras

Cameras whose orientation and zoom level can be controlled.

Path planning

Planning the vessel's route and speed according to optimization criteria such as travel time, distance, and risk of collision with other vessels.

Point cloud

A collection of distance measurements in a three-dimensional coordinate system as produced for example by a lidar sensor.

Positioning

Determining a vessel's location and orientation.

Radar (radio detection and ranging)

A sensor which uses radio waves to detect the range, angle, and velocity of objects.

Redundancy

Duplication of critical components or functions of a system to increase reliability.

Data registration

Mapping data from multiple types of sensors to a shared coordinate system.

Regression model

A model used for predicting the value of a target variable based on one or more input variables.

Reinforcement learning

A class of machine learning where a model learns behaviour strategies for maximizing some reward by interacting with the environment.

Rule-based system

A system which uses human-defined rules to manipulate or store data.

Semantic information

Syntactic information that a physical system has about its environment; information that is somehow meaningful for the system.

Semantic segmentation

Assigning a class label to each element of data, for example individual image pixels.

Sensor

A device that is used to record that something is present or that there are changes in something.

Sensor calibration

> *Measuring sensor outputs in their final installation configuration against known references to evaluate and remove consistent structural errors in the sensor outputs.*

Sensor fusion

> *Combining data from multiple sensors to achieve benefit e.g. in accuracy or reliability.*

Sensor resolution

> *The smallest change that a sensor can detect in the quantity it is measuring.*

Sensor signal synchronization

> *Aligning data from multiple sensors using a global timing signal reference.*

Situational awareness

> *Perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status.*

SOLAS convention

> *The International Convention for the Safety of Life at Sea (SOLAS) is an international maritime treaty which sets minimum safety standards in the construction, equipment and operation of merchant ships.*

Sonar (sound navigation ranging)

> *A technique that uses sound propagation to navigate, communicate with or detect objects on or under the surface of the water.*

Spatial information

> *Information about an object that can be represented by numerical coordinates in a geographic coordinate system.*

Spoofing

> *Disguising a communication from an unknown source as being from a known, trusted source.*

Supervised learning

> *Training an ML model using both data and metadata indicating the inferences the model should produce from the data.*

Thermal camera

> *A camera that creates images using infrared radiation.*

Time of closest point of approach (TCPA)

> *The estimated time of ships passing at their closest point of approach (CPA).*

Transfer learning

> *Training an ML model with new data using an existing trained model as the initial configuration.*

True negative

> *In object detection, correctly not detecting an object.*

True positive

> *In object detection, correctly detecting an object.*

Unsupervised learning

> *Training an ML model without labels, or metadata indicating the data contents.*

Voronoi diagram

> *Partition of a plane into regions close to each of a given set of objects.*

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