Regulating Autonomous Ships—Concepts, Challenges and Precedents

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Regulating autonomous ships
- Concepts, challenges and precedents

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Abstract

The article seeks to contribute to the development of a conceptual framework for the on-going regulatory discussions on autonomous ships at IMO. Section 2 elaborates on the distinction between the level of autonomy and the level of manning and highlights the sliding scale that features in both. In section 3, certain building blocks that are needed for regulating autonomous ships are identified, followed by an assessment of how key existing IMO rules deal with the challenges and an analysis of available precedents. The conclusion is that the on-going exercise is unique, almost without precedent, and that the work that has just started at IMO, so far at least, fails to address the most important - and complex - regulatory challenges.

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1. Introduction

The international debate on autonomous and unmanned ships, which has gathered significant momentum in the past few years, has recently commenced at the main international regulatory body for shipping, the International Maritime Organization (IMO). The starting point was the decision taken by the organization in 2017 to carry out a 'regulatory scoping exercise' of the challenges linked to the introduction of 'Maritime Autonomous Surface Ships' (MASS).[1] The aim of the scoping exercise is to "determine how safe, secure and environmentally sound [MASS] operations might be addressed in IMO instruments". The first substantive discussions on the topic were held in May 2018,[2] where a working group was tasked to "develop a framework for the regulatory scoping exercise, including aims and objectives, methodology, instruments, type and size of ships, provisional definitions and different types and concepts of autonomy, automation, operations and manning to be considered".[3] In a first phase 12 IMO conventions under the purview of the organization's Maritime Safety Committee (MSC) will be reviewed on the basis of a scheme for assessing the regulatory challenge that various degrees of autonomous shipping pose for each provision in the selected instrument.[4] In a second phase, potential regulatory solutions to address MASS will be analysed.[5] The exercise is to be completed in 2021 and the current terms of reference do not include the development of any rules in the field. Whether this work will eventually result in new requirements, or amendments to the existing ones, is to be decided at a later stage.

In view of the very early stages of the debate, many issues are still unclear and views differ widely between stakeholders on the nature and scope of the task. In addition, there is inconsistency in the usage of key concepts and terminology. Since uncertainties on these matters risk to complicate the further debate, it is meaningful to seek to streamline the understanding of key concepts and relationship at an early stage.

With such aspirations in mind, the present article seeks to clarify some of the key features and terminology related to automation in shipping and illustrate how the different concepts interlink and relate to each other. A proposed framework for distinguishing the key elements involved in the regulation of autonomous ships, and the grey-scales involved, is outlined in section 2.

The regulatory challenge is assessed in more concrete terms in section 3, through specific legal hurdles and past practice by the IMO to regulate

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[1] IMO Docs. MSC 98/23, MSC 98/20/2 and MSC 98/20/13.

[2] A total of 19 submissions were made by various delegates on this topic at the 99th meeting of the Maritime Safety Committee. For a summary, see IMO Doc. MSC 99/WP.1, para. 5.

[3] IMO Doc. MSC 99/WP.1, para. 5.25.1. A summary of the discussions in the working group is given in IMO Doc. MSC 99/WP.9.

[4] IMO Doc. MSC 99/WP.9, Annex 1 with appendices. The methodology is still being developed. A correspondence group is specifically set up to test the framework and methodology of the scoping exercise on the basis of a few examples. See IMO Doc MSC 99/WP.1/Add.1, para 5.30.

[5] IMO Doc. MSC 99/WP.9, Annex 1, para. 10.

automation in shipping, with a particular focus on bridge operations.[6] The more detailed review of automation in relation to three key bridge functions (operations, situational awareness and decision-making) emphasizes the difference between 'autonomy' and 'automation' and discusses the relationship between different aspects of automation and between past precedents and the existing challenge. Crew functions performed remotely, from a location outside the ship itself, is discussed as a fourth category. The examples are drawn from three main IMO conventions that are deemed to be of particular relevance to the matter: the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention); the International Regulations for the Preventing of Collisions at Sea, 1972 (COLREGS); and the International Convention for the Safety of Life at Sea, 1974 (SOLAS).

The final section returns to the challenge facing the IMO in this area, in the on-going scoping exercise and in the longer term, should it decide to proceed with regulatory reform in this field. Some thoughts are shared as to how the efforts could be prioritized to benefit most from the organization's willingness to invest resources in this topic in the years to come, and to reduce the risk that diverging national rules and interpretations will dominate the regulation of autonomous ships in the future.

2. Conceptual framework

2.1 The different elements of automation

Automation, understood as the performance of tasks through machinery rather than by human beings, can be understood both as a development in relation to manning levels and a development in relation to the level of autonomy (independence) of operational functions.[7] In addition, a key feature of unmanned shipping is the increased importance of tasks executed remotely, away from the ship itself. All three elements represent crucial aspects of the developments towards autonomous shipping and they are closely interlinked and dependent on each other. Nevertheless, they are separate issues which are often confused in the current regulatory discussions.[8]

The legal questions and challenges linked to autonomous shipping, as well as the solutions needed for resolving them, will differ depending on what choices are made in relation to manning, crew location and autonomy level. The level of

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[6] The focus of the review is a hypothetical large commercial cargo ship in international trade carrying non-dangerous cargo. Attention will accordingly not be given to special considerations relating to passenger ships, small ships, hazardous cargoes or ships exclusively trading in the national waters of one state.

[7] In the following, the term 'automation' is used broadly to cover any development involving a shift of tasks from human beings to machines. 'Autonomy' is a more limited aspect of this development which specifically addresses independence in relation to decision-making. See further in sections 2.3 and 3.4 below.

[8] For example, in the Finnish submission MSC 99/5/6 six international efforts to categorize the level of autonomy on ships are listed. Three of them consider remotely operated ship as a distinct category of autonomy. See also the IMO working group's own grading of autonomy presented in section 2.6 below.

manning, for example, is to be separated from the location of the crew, since a ship's bridge that is continuously attended from a remote location, raises different legal questions from the scenario where the bridge is completely unattended. The challenges with an unattended bridge in turn depend on whether crew members are available (on board or remotely) at short notice to intervene or if the ship's equipment is expected to resolve all situations autonomously.

If applied to concrete questions, each requirement or function needs to be assessed separately. For example, the acceptable manning levels will depend on whether the manning in question relates to the entire ship, the bridge, the engine, or individual functions, such as mooring, loading/unloading etc. Some legal hurdles manifest themselves as soon as the watchkeeping officer leaves the bridge unmanned, even for a very brief period of time, while other requirements, such as the duty to have a master or a ship security officer on board, can - in theory at least - be met as long as a single crew member remains on board the ship.

Similarly, the location of the crew may differ from one task to another. It is quite possible to envisage that certain functions that are technically easy to relay and perform remotely, such as radio communication, could be transferred away from the ship, while others, such as maintenance, will be performed by on-board crew. To the extent that bridge functions can technically be performed from a different location, which is beginning to include key functions such as lookout and manoeuvring, the removal of the function from the ship to shore is likely to be a key aspect in the development towards unmanned ships. However, remote operation is not, strictly speaking, a measure that affects the manning numbers or the ship's level of autonomy. It only affects the location from which the function is performed.

The legally acceptable autonomy level also differs from one function to another. Fully autonomous deck equipment operations (e.g. for unloading or mooring purposes) are easier to accept than bridge operations that are heavily regulated and involve obvious risks for third parties and for maritime safety. Even for bridge operations the level could vary. A ship could, for example, have an autonomous navigation system in place for avoiding close contact with other ships, but manual intervention would still be required for dealing with close quarters encounters or emergency situations at sea.

For present purposes, a simplified two-dimensional figure suffices for distinguishing the key issues involved.[9] In the figure below the vertical axis addresses the level of *on board* manning and thus combines the level of manning and the location of the crew. The horizontal axis addresses the level of autonomy.

[9] See also the Danish Study ''Analysis of Regulatory Barriers to the Use of Autonomous Ships", Ramboll & Core, 2017, enclosed to IMO Doc. MSC 99/INF.3, at, p. 7.

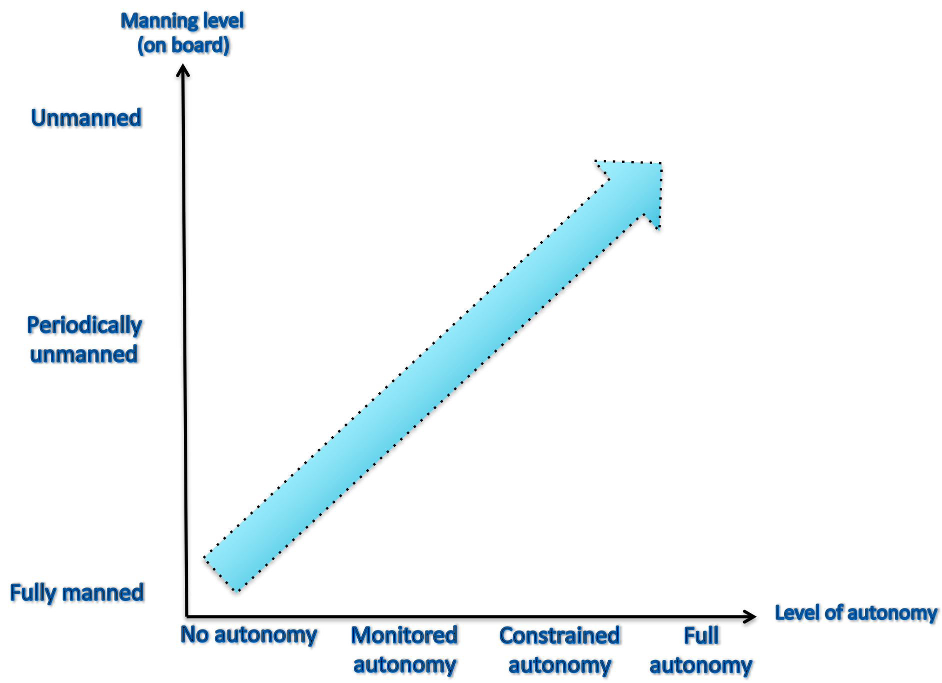

Figure 1: Separating the two key aspects of ship automation

The figure highlights the sliding (non-binary) nature of both axes, which are discussed in more detail below. Generally, legal (and policy) controversy tends to increase the further up the arrow one moves in the graph, but the development is not linear.

It should finally be noted that the temporal scale governing the different elements differ. The on-board manning level of a ship will normally not change frequently and a particular ship will, therefore, generally have a fairly fixed position on the vertical axis in the graph. By contrast, the autonomy level may differ during a single voyage, as it may be altered depending on the sailing area, traffic conditions etc.

A solid regulatory framework for automated shipping operations should be able to deal with such variations and should not be limited to a specified level of manning or automation. It will probably have to be introduced step-by-step in view of the many elements involved and the difference in technological availability, commercial demand and political acceptability. In the following, the focus lies specifically on the legal challenges linked to automation of *bridge functions* and *navigational decisions*, such as collision avoidance.

2.2 The level of on board manning

The bottom of the vertical axis on manning level is the 'fully manned' condition. This signifies the (minimum) level of manning, watchkeeping and other duties on board ships which are currently required by international rules. As long as this level of manning does not change and the crew's role and responsibilities remain intact, it is not legally problematic to automate bridge operations to assist the crew or even to support it in navigational decision-making. Indeed, the existing requirements for on board navigational equipment are minimum requirements and navigators are specifically encouraged to make use of multiple sources of navigational equipment.[10] Legal issues will, however, start to surface, either when the level of autonomy is increased to the extent that navigational decisions are made autonomously (discussed below in section 2.3), or when the level of manning is altered as a consequence of automation.

At the high end of the axis, the ship is entirely unmanned and all functions need to be performed either remotely by a shore-based crew or autonomously. The removal of the crew from the bridge faces a number of legal hurdles in the existing international rules, notably the requirements on watchkeeping and on the safe manning of ships.[11]

In between the two extremes there is a large range of more or less 'periodically unmanned' variants, where the bridge is physically manned part of the time. For the rest of the time, no person on board is in charge of the watchkeeping duties and the ship is operated either remotely from a shore-based control centre or autonomously, or through a combination of these.[12] In contrast to the completely unmanned bridge, this option entails that some competent crew members are retained on board who can act on alerts and assume control over the operations where needed.[13]

Periodically unmanned bridges offer a broad spectrum of applications at various autonomy levels. In a 'light' format, the availability of competent crew members at short notice could, for example, be used to permit the crew to leave the bridge in non-congested waters and leave only the situational awareness function to automated systems. The ship would then hold a given course and could alert the crew's attention to various dangers through alarms based on pre-determined parameters. In a somewhat more developed variant, the system would autonomously perform pre-programmed steering manoeuvres to avoid close contact with other ships or shallow waters, but would alert crew members to assume control in situations in which those parameters could not be met, in good time before a dangerous situation arises. At the other end of the spectrum for periodically unmanned bridges, the ship would be operated autonomously or

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[10] See e.g. COLREGs Rule 7(a): "Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists" and STCW Code A para. 27: "officers of the navigational watch shall make the most effective use of all navigational equipment at their disposal."

[11] These tensions are discussed in more detail in section 3.5 below.

[12] To meet this status, the presence of the on-board crew has to be continuous. In other words, a ship that is operated entirely without a crew for some voyages and is fully manned for other voyages does not fall within this category, nor does a ship to which the crew is physically brought in only when the ship approaches shore or a congested sea area.

[13] It should also be noted that the distinction between unmanned and periodically unmanned is not straightforward. Whereas a completely unmanned bridge presumably refers to the situation where no officer in charge of the navigation is physically on board the ship, periodically unmanned ships may appear in different variations, depending on the crew's availability to returning to service, the duration of stand-on time etc., all of which will affect the measures needed to implement the scheme.

remotely for most of the time while a single officer/master remaining on board would be called to the bridge only at port approaches or in exceptional situations.

The periodically unmanned bridge involves a number of legal differences from its completely unmanned counterpart. The presence of a competent bridge crew on board offers an easy means of avoiding several of the legal challenges posed by entirely unmanned bridges as there will be individuals on board to perform functions that specifically require a physical presence. The ship will (presumably) also have a captain on board to perform the functions associated with that position and various special obligations that relate to dealing with emergencies can be handled in a traditional way. However, for the unmanned periods, periodical manning does not differ from a completely unmanned bridge in terms of the need for a solid legal basis for operating without a crew.

The legal solutions for dealing with maritime events will also differ between periodically unmanned bridges and fully unmanned ones. A key part of the regulatory solution to permit periodically unmanned operations lies in securing intervention when needed, which in turn requires proper monitoring, situational awareness and on-board alerts and alarms as well as adequate standards for the crew's readiness to be on call.[14] A completely unmanned bridge, by contrast, needs more regulatory attention to redundancy functions and operation in case the communication links to the control centre are lost.

Periodically unmanned bridges have not received much attention to date, as the principal studies have so far focused on (completely) unmanned ships. However, including this midway category seems particularly relevant. This is both because this type of 'lighter' solution is more likely to be implemented in practice in the short-term,[15] and because any type of unmanned operation of ships, even in a light and temporary format, raises legal issues which the current legal framework does not properly address.

2.3 The level of autonomy

The level of autonomy concerns the division of tasks between humans and automated systems in complex decision-making processes, such as bridge watchkeeping functions. The area spans from full human involvement in the operations to fully autonomous systems that operate without any human interference. Increasing the autonomy is hence concerned with removing human involvement in a much more fundamental sense than only shifting the location of the persons involved. Autonomy in a navigational context signifies that human decision-making on board is replaced by IT-based solutions on the basis of pre-programmed algorithms and/or computer-based learning. The more autonomous the function is, the more alienated the operation from traditional navigational practices, and legal issues start to surface. For example, the collision

[14] See also the regulatory solutions accepted for periodically unmanned machinery spaces referred to in section 3.3 below.

[15] Both remotely-operated and autonomous operations are currently being explored by equipment manufacturers for covering the unattended watches. See e.g. O. Levander, 'Autonomous ships on the high seas', *IEEE Spectrum*, vol. 54, no. 2, pp. 26-31, February 2017.

avoidance rules in the COLREGs presume that a human is in the decision-making loop as they are subject to the "good seamanship" of the individuals in charge of navigation and as navigational decisions are not supposed to deviate from the "ordinary practice of seamen".[16] 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.

In the graph in Figure 1, two mid-levels of autonomy are introduced between no autonomy and full autonomy.[17] The 'monitored autonomy' 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 satisfactorily. In this, largely theoretical, construction the autonomous system offers decision-support for the crew, but involves no alteration of their role or responsibilities. In the 'constrained autonomy' option this changes. Here the automated system operates the ship independently and without 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.

From a legal point of view the critical issue is the control over navigational decisions, rather than the level of sophistication of the system. Hence the most important point, for authorising autonomous operations, but also in terms of responsibility and liability, lies at the point where 'monitored autonomy' turns into 'constrained autonomy'. It is at this point that the system is (partially) 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 in an autonomous mode are less significant for defining the legal challenge.

The level of autonomy is not static on a ship, as it is determined by operational parameters, rather than by the equipment available on board. In other words, the mere fact that a ship has the *capacity* to operate in an autonomous mode does not make it legally autonomous. It is the actual operation of the ship at the relevant time that matters. The autonomy level may very well change during a single voyage, depending on the trading area and the traffic conditions etc. A legally relevant question in this regard is also how the level of autonomy is determined. Will it be decided manually by the persons in charge or will the system itself decide on the required level of human attendance?

2.4 Links between the elements

The discussion above has emphasized the importance of separating the different elements of automation. Despite this, it is clear that the elements of automation

[16] COLREGs Rules 2 and 8. See further section 3.4 below.

[17] There is no consensus on this categorization, in a maritime context or otherwise. See e.g. IMO Doc. MSC 99/5/6 referred to above. The categorization also depends on whether the focus lies on control, decision-making authority, level of oversight required or the extent to which the crew may be relieved of its tasks. The present four-stage division is chosen as it is considered that four levels of autonomy suffice for highlighting the main legal issues involved.

are closely linked and intertwined. For example, the more on-board manning is reduced, the more support/solutions are needed from autonomous systems and/or shore-based crews. Similarly, with the increasing autonomy of ships' functions there will be less meaningful tasks for the crew, wherever located, to perform.

Remote operation in itself presumes a certain reduction of crew numbers. It will not be feasible to have the full bridge crew removed to a shore-based control centre in view of the differences in the task that can be performed remotely. Lookout functions, for example, would largely have to be replaced by technological solutions in a remotely operated ship.

Moreover, a bridge which is entirely unmanned and remotely operated requires a certain degree of autonomous navigational functions. The ship needs to be able to navigate safely, or at least survive, if the contact to the shore-based control centre is lost. Communication between the ship and shore may also be limited by reduced bandwidth capacity, radio disturbances and other entirely foreseeable risks. A certain degree of autonomy accordingly seems necessary for remotely-operated ships, even if they are fully attended by shore-based crew. Even a partial manning on board significantly reduces the need for covering such issues and offers a broader range of solutions for regulatory compliance.

2.5 On the nature of the legal challenge

Making use of technology to support ships' crews in performing their duties is not legally problematic as such. It is only when the role and responsibility of the crew is altered that legal tensions begin to accumulate. Different types of challenges appear depending on whether the development relates to the level of on board manning or level of autonomy. In the former case, the key legal hurdles are formed by existing requirements demanding physical presence on the bridge and by a range of requirements in several conventions that require on board crews to perform various duties. In the latter case, the main hurdles are the rules that specifically presume the presence of humans in the decision-making loop.

It follows from the above that such legal hurdles may arise quite early when moving along the direction of the arrow in Figure 1. Moving upwards in the graph by reducing the on-board manning, the first legal problems arise as soon as the officer on watch leaves the bridge or associated location. The problems linked to (periodical) reduction of the bridge crew concern all levels of autonomy, and the crucial question of whether the crew's tasks can be assumed by crew member from a remote location is not settled in any of the existing legal instruments.

The autonomous mode of operation can similarly be activated even at comparatively low levels of autonomy (and where only a very limited range of functions are autonomous). Even a ship navigating with the aid of a relatively simple device, such as an advanced auto-pilot that operates to actively avoid close contact with other ships and alerts the crew in cases where this cannot be done, will be acting autonomously as long as the crew is not expected to monitor and control the device's operations. Incidents taking place in a 'constrained' autonomous setting, even if only caused by a faulty alarm, raise the same issues of principle as incidents caused by more sophisticated ship autonomy equipment.

The above observation may be illustrated in the figure below by adding a rough categorization of the legal challenge involved to the graph used in Figure 1.

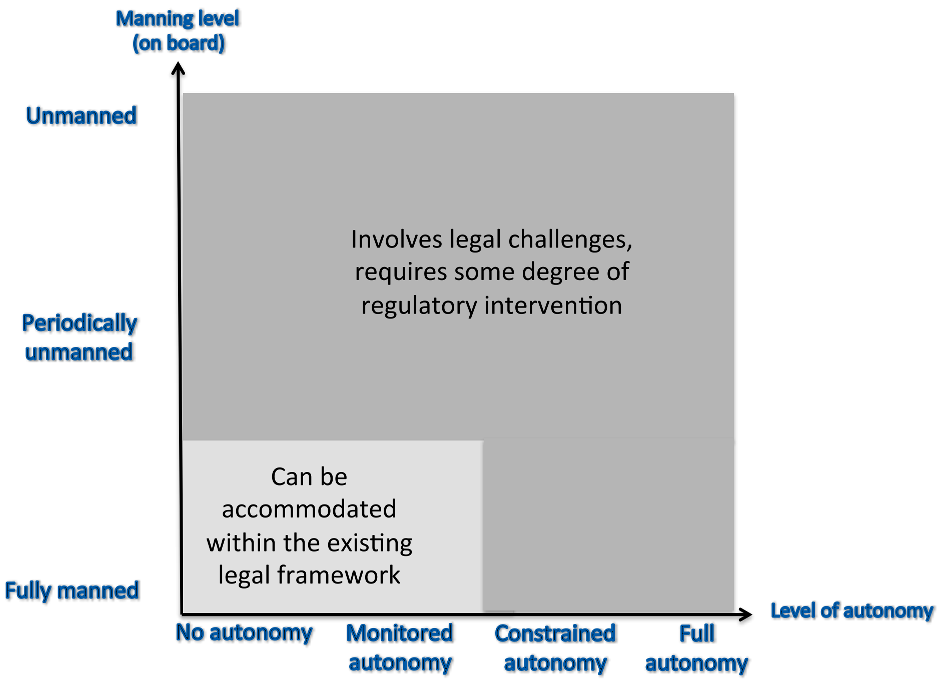

Figure 2: Nature of the legal challenge.

2.6 The degrees of automation at IMO

In the early phases of the IMO discussions on ship autonomy,[18] the focus was exclusively placed on (entirely) unmanned ships. This permitted a simple autonomy grading between remote control and full autonomy, i.e. at the highest level of the vertical axis in Figure 1 above. Since then, the debate has broadened and various degrees and modes of manning, without counterparts in e.g. road traffic, have entered the scene. The coverage of periodically unmanned ships has made the regulatory picture considerably more complex, in theory as well as in practice. However, since periodically unmanned ships represent a natural step in the development towards completely unmanned ships, which could also be of considerable interest to commercial players, it is both relevant and necessary to include the differentiation of manning levels and modes in the regulatory discussions.

At least so far, a separation between the different aspects of automation has not received much attention in the international discussions. The IMO's working

[18] Including the quasi-totality of submissions to MSC 99 referred to in note 2 above.

group has merely identified four 'degrees of autonomy', to facilitate its work. The four degrees are:

> 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.[19]

The mixing between levels of autonomy (1 and 4) and manning (2 and 3) in the four points risks generating confusion in further regulatory debates. In addition, and perhaps more importantly, the working group's desire to keep the number of variables low, has omitted any grading of the levels on the axes. Many issues that are of crucial relevance for the scope of the challenge and for the available solutions, and are at the same time the most relevant from a commercial perspective, such as the periodically unmanned bridge or the partially autonomous functions, are not therefore included in the exercise as currently defined.

3. Nature of the legal challenge of the IMO - categories and precedents

3.1 Introduction

To establish the more concrete nature and scope of the legal challenge facing the IMO, should it decide to regulate autonomous ships, it is necessary to identify the relevant building blocks of the exercise. This section identifies four categories of functions that need to be automated to achieve (partly) autonomous bridges and discusses some key legal hurdles in the way. It also considers whether and to what extent certain aspects of automation have already been addressed by the IMO.

Three of the four categories deal with the automation of functions, i.e. the replacement of three key bridge functions by technical solutions: operational tasks, situational awareness and decision-making. Only the last category, the automation of decision-making, represents autonomy in a strict sense, while the other two are better described as 'automation'.[20] However, all three categories of functions need to be addressed to enable a development towards autonomous ships.

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[19] MSC 99/WP.9, Annex 1, para. 4. See also the Danish study referred to in note 9 above.

[20] See also the 'Definitions for Autonomous Merchant Ships', issued by the Norwegian Forum for Autonomous Shipping (NFAS), available at http://nfas.autonomous-ship.org/resources/autonom-defs.pdf, at pp. 5-6: "*Automation* is used as a general term for the processes, often computerized, that make the ship able to do certain operations without a human controlling it. *Autonomy* is the result of applying "advanced" automation to a ship so that it implements some form of self-governance, i.e. that it can select between alternative strategies without consulting the human."

Autonomy, too, exists at different levels of technical sophistication. While less advanced autonomous systems make their navigational decisions based on algorithms and software that have been pre-programmed (by humans) for the purpose, more advanced autonomous operation systems can be self-learning in the sense that they develop their decision-making on the basis of experience, possibly using artificial intelligence for the purpose.

The figure below represents an effort to schematically illustrate the relationship between the categories of automation discussed below.

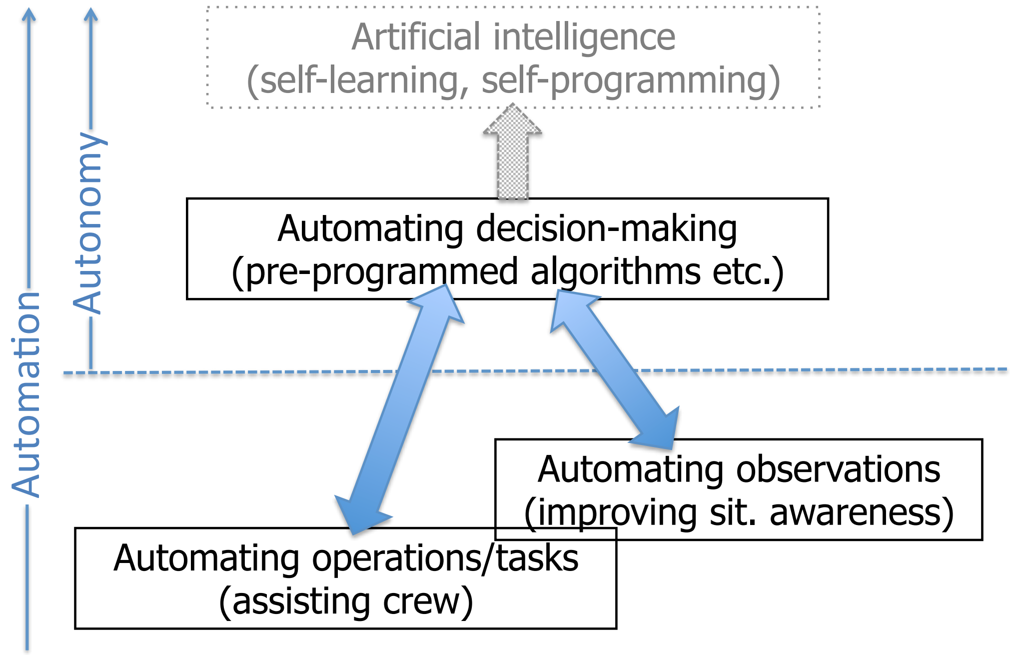

Figure 3: Different categories of automation required for automating bridge functions

In addition, a fourth category of regulatory intervention is needed for the relocation of functions away from the ship/bridge. Remote control is not, strictly speaking, about automation, but is in practice closely linked to the development of autonomous shipping.

The extent of the regulatory challenge is illustrated by the submission that the existing precedents at the IMO offer (partly) relevant guidance for only two of the four categories. For the remaining two, the organization enters uncharted territory.

3.2 Automating operations (assisting bridge crews to perform operational tasks)

The first category of automation is the use of technology to help the crew perform certain operational functions that have traditionally been undertaken by humans alone. Such aids to crew members, including bridge crews, have been accepted for decades and have sometimes been formally endorsed in conventions and/or through specific performance standards for the relevant equipment.[21]

An early example of this type of technical aid in the field of navigation operations is the autopilot, which has been in use on board ships since the early days of navigation and is even a mandatory piece of equipment for larger ships under SOLAS.[22] A much more advanced example is the Dynamic Positioning (DP) system, which is based on sophisticated instrument and control integration enabling the ship to be manoeuvred much more accurately than humans could ever do manually. In terms of standards, too, DP represents a high level of sophistication, by defining three different levels of automation and including requirements related to redundancy, crew training as well as governmental supervision and control.[23] All of this, which is currently regulated by means of non-binding resolutions only, could be of significant interest when seeking models for developing standards for autonomous ships.

Nevertheless, even if technically sophisticated, these examples do not interfere with the ultimate control and responsibility of the crew members, who still need to supervise the operations and may interfere with the operations at any time should the need arise.[24] Consequently, even the DP system does not challenge existing requirements in relation to the role of the crew, command structures or the chain of responsibility, but remains an aid that can be added 'on top of' the existing bridge equipment standards at the option of each owner, without causing a legal conflict in relation to existing rules.

However, IMO practice also includes less successful examples of efforts to automate operations. The prime example is the ultimately unsuccessful experiment with one-man bridge operations in periods of darkness. In this case the practice did cause some friction with current manning rules, even if it did not affect the responsibility of the officer of the navigational watch. Legal concerns were presented as part of the opposition, but the main objections were linked to maritime safety and to general shipping policy.

> The overriding principle regarding a look-out for both the COLREGs and the STCW is that a proper look-out shall be kept at all times. In the original STCW Convention from 1978 it was already accepted that a single person may perform the duties linked to watchkeeping, including the look-out, provided certain conditions were met.[25] In the late 1980's pressure increased to extend the one-man operation further to include the hours

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[21] The first documents on increased automation in shipping were introduced as early as 1964 and remain surprisingly relevant for the matter currently under discussion. See e.g. IMCO Doc. MSC VIII/11 entitled 'Automation in ships' and the related discussions.

[22] Reg. V/19.2.8

[23] The original Guidelines for vessels with dynamic positioning systems from 1994 (MSC/Circ.645) have been replaced by a new set of Guidelines for vessels and units with dynamic positioning systems from 2017 (MSC.1/Circ.1580).

[24] See e.g. para. 4.3. providing that higher-class DP operations "should be terminated when the environmental conditions (e.g. wind, waves, current, etc.) are such that the DP vessel will no longer be able to keep position if the single failure criterion applicable to the equipment class should occur."

[25] STCW 1978, Reg. II/1.9. See also Section A-VIII/2, of the STCW Code, para. 15.

of darkness as a mechanism for reducing operational costs, provided certain requirements were met.

The work initiated by the IMO in 1989 eventually resulted in a framework for trials for this purpose.[26] The trials were only open for ships specifically designed for the purpose through the use of sophisticated bridge integration systems and alarms that would prevent the watchkeeping officer from falling asleep. Between 1991 and 1996 a number of trials authorised by flag states were undertaken,[27] and a parallel process for amending the STCW Convention to permit solo watchkeeping in periods of darkness was initiated.[28]

Throughout the trials, there was significant resistance towards these plans. According to the opponents, the trials were questionable until they were proven to be safe and the STCW was amended to authorize the practice. Legal concerns were also raised in relation to the lookout and watchkeeping requirements of COLREGS and STCW.[29] From an early stage, certain states, led by the US, demanded that ships participating in the experiment should not be allowed to navigate in their coastal waters. The IMO Secretariat kept a record of the states that would not permit ships participating in the trials to do so in their coastal waters.[30]

Due to the significant policy concerns the trials were eventually discontinued, much to the frustration of the states supporting the trials who noted that there had been no safety concerns with the ships participating in the trials.[31] Consequently, the proposed draft amendments to the conventions were also withdrawn. The only remnant of the debate today is the strictly worded provision for when flag states may authorize tests deviating from the STCW Convention. This provision, STCW Regulation I/13 is discussed further in section 3.5 below.

On the basis of these examples, it seems that the relationship with existing rules is key to determining the scope of the legal and political challenges linked to automation of operational tasks. As long as automation is only placed on top of the existing rules, without causing tensions with them, even far-reaching forms of automation can be accepted. Conversely, if the automation has involved changes to the existing rules, especially regarding the role and responsibilities of crew members and the minimum manning standards as laid down in the STCW, automation has been more difficult to achieve, even on a trial basis.

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[26] MSC Circular 566 of 2 July 1991 ('Provisional Guidelines for the Conduct of Trials in which the Officer of the Navigational Watch acts as the Sole Lookout in Periods of Darkness').

[27] For a detailed summary of the trials, see IMO Doc. NAV 40/WP.1 Generally, the ships participating in the trial operated safely. It was, *inter alia*, noted that the most important factors to the safety of solo watchkeeping in periods of darkness included: continuous vigilance by the officer on watch; the use of automated systems to reduce the officer's workload during the watch; and familiarity with all bridge equipment and its limitations, and procedures relating to solo watchkeeping, particularly with respect to calling for assistance and suspending solo watchkeeping. IMO Doc. NAV 45/25, para. 10.13.

[28] IMO Doc. NAV 40/25, Annex 18, Annex. The draft requirements included both design and equipment standards for the bridge, alarm systems and qualification requirements to ensure familiarity with the ship and specific duties and responsibilities of the master and the officer of the navigational watch.

[29] See e.g. IMO Doc. MSC 59/11/4.

[30] See e.g. IMO Doc. NAV 40/25, Annex 18, para 6.s:

[31] IMO docs. MSC 65/25, paras 9.9-9.19, MSC 66/24, paras. 7.31-7.39. A new circular MSC/Circ.733 was adopted at MSC 66 in 1996 announcing the discontinuation of the trials. See also MSC 69/22, paras 21.16-21.39.

3.3 Automating situational awareness (replacing the human function of observation)

A second category of crew functions that will require automation concerns information about the circumstances on board the ship and in its surroundings, i.e. situational awareness. In other words, can electronic instruments and equipment replace the human function of observation? This type of automation is a precondition for both remote and autonomous operations and there are some potentially relevant regulatory precedents within the IMO.

An early example is the optional replacement of the physical watchkeeping of the crew in the engine room by various forms of sensor equipment and alarms, through guidelines and standards; these standards eventually ended up as a new section in SOLAS (Chapter II-1, Part E) on 'periodically unattended machinery spaces'.[32] Part E sets out the basic requirements on sensors and controls for monitoring and responding to machinery operating conditions; this makes it unnecessary for personnel to be present in the space at all times. The main principle of Part E is to ensure an equivalent safety standards to manned machinery spaces, in all sailing conditions.[33]

The rules do not include detailed specifications of the requirements and several of its provisions are open to interpretation. Individual flag states and classification societies have accordingly developed their own rules and notations for approving periodically unmanned machinery spaces.[34]

Most larger ships today meet the required standards for unattended machinery spaces, which usually has the practical effect that that they can have their engine crew working 'office hours' with the automated systems keeping a watch in the remaining 16 hours of the day. For present purposes, it is important to note that the requirements do not imply the removal of the entire engine room crew from the ship. On the contrary, both the STCW requirements and the class notations assume that engine crew is readily available to intervene - at any time of the day - should the need arise.[35] This example is thus located relatively high up on the

[32] Specific requirements for unmanned machinery spaces have subsequently also been included in the STCW Code.

[33] Reg. II-1/46(1). The rules include means for early detection fires (Reg. 47) and flooding (Reg. 48) in the machinery spaces. It is required that the propulsion machinery is fully controllable from the navigation bridge and various conditions for those controls are set in Reg. 49. A reliable means of vocal communication between the various control stations is required (Reg. 50). The chapter also includes certain requirements on other machinery, including power generation, and a number of requirements on indicators and fault alarm systems (Regs. 51, 53(4)) as well as a shut-down safety system in case of immediate danger (Reg. 52). Specific (additional) requirements apply for passenger ships (Reg. 54).

[34] For example, the term 'periodically' is not specified in SOLAS, which makes it unclear how long the machinery spaces may be left unattended. Presumably, normal maintenance places the limit, rather than formal time limits. The DNV class notation E0, by contrast, provides that that "the extent of automation shall be sufficient to permit unattended engine room operation for 24 hours." (DNV E0 notation, v. 2011, section 2, para. A 100).

[35] See STCW Code A VIII/2, Part 3-2, para. 64. "When the machinery spaces are in the periodic unmanned condition, the designated duty officer in charge of the engineering watch shall be immediately available and on call to attend the machinery spaces." The 2011 DNV E0 notation, similarly provides that "[t]he assignment of class notations E0 and ECO is based on the

manning level axis of Figure 1, and is the only known example of a technical solution specifically aimed at altering the role of the crew. The regulatory process for arriving at this outcome was not a rapid procedure. The matter was discussed at the IMO since the mid 1960's before finally being introduced into SOLAS in 1974.

Another precedent of more immediate relevance to bridge crews relates to compliance with the lookout requirement in COLREGs Rule 5:

> “Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.”

Even if the duty is placed on the 'vessel' rather than on human beings, the use of words referring to human qualities such as "sight and hearing" clearly suggests it is intended to cover human lookout functions. The rule applies "at all times" and COLREGs offers no exemptions or possibilities for equivalent standards.

Nevertheless, subsequent technical developments have paved the way for a more flexible interpretation of the requirement. Notably, the increased use of enclosed bridges has posed challenges for compliance with the hearing requirements for decades. Alternative solutions have been accepted, first informally through class requirements, and then subsequently through a formal amendment of SOLAS. Regulation V/19(2.1.8) now provides that all ships:

> "when the ship's bridge is totally enclosed and unless the Administration determines otherwise, [shall have] a sound reception system, or other means, to enable the officer in charge of the navigational watch to hear sound signals and determine their direction".

The wording effectively modifies COLREGs Rule 5, through another convention, and clearly accepts the prospect that human functions may be replaced by technology, at least as far as situational awareness is concerned. Moreover, in contrast to the COLREGs rule, the quoted SOLAS paragraph grants a wide discretion for (flag state) administrations to approve alternative compliance solutions.

Whether that same logic could be extended to replace the entire lookout function as required in Rule 5 is more uncertain. The matter depends on whether the wording and spirit of Rule 5 is broad enough to authorize a replacement of the human lookout by various types of cameras, radar, audio technology and other technical solutions, assuming that the technologies used are at least as effective and safe as with diligent humans performing the lookout functions.

Even if the wording of Rule 5 is straightforward, it is not entirely unconditional. It was noted earlier that the obligation rests with the vessel, without further specification. Moreover, the use of terms such as “proper” and “appropriate” provides for some flexibility as regards how such a lookout is to be organized on board. It has accordingly been proposed that the term lookout, as used by the

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assumptions that: engineering staff can attend the machinery space at short notice" (section 1, para. A 204).

Rules, does not necessarily denote a person, but rather the systematic collection of information.[36] If that interpretation is accepted, the threshold for approving a technological replacement for the human look-out becomes considerably lower.

The purpose of the lookout rule is arguably to make sure that whoever controls the ship is aware of the circumstances on and around the ship to make informed decisions with respect to actions to avoid collisions and other incidents. The above example with a sound reception system for enclosed bridges illustrates that a strictly literal interpretation of the "sight and hearing" has not been adopted by the IMO in the past.

On the basis of such considerations, it is arguable that a broader automation of the lookout functions could be accommodated within the existing wording of COLREGs, provided that the technical performance of the equipment allows the person in charge of the ship to have an overview of the circumstances which is the same or better than through a human lookout; thus allowing him/her to take appropriate action in good time. However, in view of the widespread authority of COLREGs and the nature of collision regulation (always involving more than one ship), it seems important that a clarification or interpretation to that effect is made at an international level, rather than by individual (flag) states.

It is important to note, however, that the current precedents only cover the *transfer* of information by electronic means. They do not cover automated *processing* of the observations made or data transmitted, which will necessarily form part of more complex situational awareness data. This would include: the prioritization of data, dealing with unclear observations and conflicting data from various sources, both generally and in the case of limited bandwidth capacity. For such issues the existing regulatory framework offers no guidance at all. The application of the principle of equivalence, under which alternative arrangements can be considered by flag states if they are at least equivalent in terms of safety to the solution foreseen in the convention, has mainly been limited to technical arrangements.[37] Neither the COLREGs nor the watchkeeping parts of the STCW includes this option.

3.4 Automating decisions (autonomous operation)

A third category of automation comes into play when technology assumes the role of the crew in operative decision-making. In this case, the equipment acts autonomously, i.e. without human involvement, at least for a period of time. In the terminology of Figure 1, this covers the constrained and full autonomy levels of autonomy. As far as navigation is concerned, this can notably be achieved through pre-programmed software that performs navigational decisions to avoid

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[36] See e.g. C. Llana & G. Wisneskey *Handbook of the Nautical Rules of the Road,* 3rd on-line edition, 2006 (updated in 2011), available at http://navruleshandbook.com/Rule5.html

[37] See SOLAS Reg. I/5 but also SOLAS Reg. I/4(b) and Art. 8 of the 1966 International Convention on Loadlines. The equivalence principle in STCW Article IX only applies to educational and training arrangements. A limited exception is SOLAS Reg. V/3 which accepts national exemptions and equivalence solutions in the field of safety of navigation 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.

collisions with other ships and objects in accordance with the COLREGs. By contrast, a ship that merely navigates along a (manually) pre-programmed route based on consecutive waypoints does not belong to this category, as in this case the system undertakes no independent decision-making of its own.

Autonomous navigation presupposes the existence of automated navigational control and automated situational awareness data. However, it represents a much more fundamental change to the current regulatory environment. Autonomous navigation challenges the authority and role of crew members and therefore raises a series of interesting legal questions, not all of which appear in the form of direct conflicts with existing rules.[38]

It is only in the past few years that technology has been available to make a move in the direction of autonomous bridge functions feasible, and in terms of regulatory examples, there is no precedent for addressing this kind of automation at the IMO. The prospect of a fully developed autonomy, in which a ship undertakes an entire voyage totally without human supervision or involvement is hardly realistic in the short-term. For the foreseeable future, at least, there will normally be some crew members available to assume, if needed, control of - and responsibility for - the ship's operation, either on board or remotely. This could even be introduced as a regulatory requirement.

Nonetheless, this consideration does not dispense with the need to address the legal hurdles linked to autonomy at an early stage. As was noted in Section 2, many issues of principle already arise at comparatively low levels of sophistication within the autonomy, and even if the ship is only operated autonomously for a very limited period of time.

Generally speaking, the technical rules represent a lesser concern in this regard, at least in terms of outright legal conflict. Technical requirements normally prescribe functions to be performed without detailing the manner in which the functions should be executed,[39] and accept a broader range of equivalence-based solutions.[40] Similarly, the safe manning requirements are fairly neutral with respect to autonomy. The goal-oriented focus of the principles for safe manning leaves space for the flag state administration to decide on whether or not a particular function could be carried out autonomously.[41] Most aspects in the

[38] Examples include the identification of the master on an autonomous ship and the scope of his/her responsibilities, questions related to seaworthiness and the distribution of liability between the various parties for damage caused by wrongful autonomous decision-making. See e.g. L. Carey, 'All Hands Off Deck? The Legal Barriers to Unmanned Shipping', *Journal of International Maritime Law* 3/2017, and R. Veal, M. Tsimplis, 'The Integration of Unmanned Ships into the *Lex Maritima*', *Lloyd's Maritime and Commercial Law Quarterly*, 2/2017.
[39] See e.g. H. Ringbom, F. Collin, M. Viljanen, 'Legal implications of Remote and autonomous shipping', in M. Laurinen (ed.), *Remote and autonomous ships. The NeXT steps*, Rolls-Royce, 2016, pp. 35 - 55 http://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf; R. Veal and H. Ringbom, 'Unmanned ships and the international regulatory framework', 23 *The Journal of International Maritime Law* 2/2017, pp. 100-118 and the CMI study in IMO Doc. MSC 99/INF.8.
[40] See note 37 above.
[41] See below in section 3.5.

guidelines that specifically address bridge crews could be performed by automated systems, provided that the performing technology is available.

The main direct hurdle in this regard are the rules that explicitly require human judgement in the navigational decision-making loop. Some key examples are found in COLREGs. Rule 2, which stipulates 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 steering rules and expressly states that in certain circumstances, deviation from the rules may be required. Rule 8(a) similarly 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 quoted rules, as with COLREGs generally, are neutral with respect to who makes the decision or from what location.[42] The legal problems arise purely in the context of autonomy. From a technical point of view, it is probably feasible to create algorithms that comply diligently with the steering and sailing rules of COLREGs, even taking into account the sometimes unpredictable actions of other ships, and the somewhat conditional distribution of rights and obligations in the rules.[43] The references in Rules 2 and 8 to 'the ordinary practice of seamen' and 'good seamanship', however, introduce abstract principles, the content of which will eventually be established in retrospect through a factual assessment of the ship's conduct based on all relevant prevailing circumstances. It seems obvious that any effort to pre-program ‘good seamanship’ into an automated navigation programme will be fraught with serious difficulties.[44] A key question is therefore to what extent the quoted provisions of COLREGs prohibit an autonomous, IT-driven, collision avoidance system.

Arguably not completely. First, it follows from the text of COLREGs that the references in question only apply in navigational situations or incidents at a developed stage. By the time the good seamanship requirements will become

[42] The subjects of the steering and sailing rules are ‘vessels’, without further details as to the person behind the decisions, while Rule 2 takes a broad approach in listing "any vessel, or the owner, master or crew thereof". There is accordingly nothing in the Rule to preclude that the human judgment is provided remotely.

[43] See e.g. Rule 8(f)(iii) providing that even "a vessel the passage of which is not to be impeded remains fully obliged to comply with the Rules of this Part when the two vessels are approaching one another so as to involve risk of collision." In addition, some rules are specifically made conditional on prevailing circumstances and conditions. See e.g. Rule 6 requiring every vessel at all times to “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” and Rule 2 quoted above.

[44] It may be also noted that the most rational decision in theory in a given situation does not necessarily always constitute good seamanship. Unannounced manoeuvres which are not commonly practiced by bridge crews, such as moving the throttle into reversing mode to avoid close contact, may seem unpredictable by fellow navigators and may hence fall foul of the standards of the ordinary practice of seamen.

relevant under COLREGs in a collision situation, for example, the ships are already quite close to each other and the risk of an incident is already high. The provisions do not therefore rule out that autonomous navigation systems could be used to avoid that ships end up in 'close quarters' situation in the first place.[45] The more cautiously the system is programmed in terms of values on closest point of approach, alarm parameters etc., the easier it will be to make the system fit within the wording and spirit of the COLREGs.[46]

Second, the acceptability of autonomous navigation systems will also inevitably depend on the manning level. If the bridge is only periodically unmanned and there is a qualified watchkeeping officer available at short notice, the system could essentially consist of a sophisticated autopilot with an alarm system to indicate, in good time, of any approaching traffic or other objects or events. A more advanced system is needed if the availability of the officer is reduced and the system is expected to handle situations autonomously for a longer period of time. Similarly, the navigation system of a periodically unmanned ship can be less sophisticated if the watchkeeping officer is physically on board the ship, rather than at a shore-based remote control centre. The latter case needs to provide solutions for ancillary risks such as loss of or delay in communication and redundancy requirements. For example, even a small and foreseeable delay in satellite-based communications between the shore-based watch and the ship may significantly affect early collision avoidance manoeuvres under Rule 8(a) or safe speed calculations under Rule 6. This risk of communication delays is so foreseeable that it raises questions as to whether 'close-quarters' situations should be handled remotely at all. This would indicate a preference for either periodically unmanned bridges with the crew on board, or even completely autonomous ship-based systems, over remotely controlled unmanned bridges.

Thirdly, the acceptable level of autonomy of a navigation system presumably also depends on more variable conditions, such as the geographical, meteorological and traffic conditions of the area in which the ship is navigating. All these will vary during a single voyage of a ship. Specifically outlining the conditions for when the autonomous navigation systems can be used would also reduce tension with COLREGs.

In conclusion, even if certain COLREGs provisions rely on a human judgment in the decision-making loop, autonomous navigation systems are not entirely excluded by the convention. The matter has not been discussed at IMO in the past, but it is submitted that such systems could be compatible with the current COLREGs wording if their operation is closely conditioned on a number of safety parameters and provided that necessary safeguards are ensured to enable

[45] The term 'close-quarters situation' features in Rules 8 and 19 of the COLREGs, but is not defined. For an effort to define it, see Helmut Hilgert, 'Defining the Close-Quarters Situation at Sea' 36 *The Journal of Navigation*, 3/1983, pp. 454-461.

[46] For an example of such parameters, very cautiously set, see E. Lehtovaara & K. Tervo, 'B0 – a conditionally and periodically unmanned bridge', 2018, available at http://new.abb.com/marine/articles-and-highlights/b0-a-conditionally-and-periodically-unmanned-bridge.

human intervention where necessary.[47] However, in view of the many uncertainties associated with the limits of their operation, further guidance would seem necessary to set out the conditions for operating such systems.

3.5 Re-locating operations (performing ship-board functions remotely)

A separate legal question that needs to be clarified is to what extent bridge functions under existing rules may be performed from a location away from the ship, i.e. whether the tasks of the bridge crew can be implemented remotely by crews based on shore or elsewhere away from the ship. A number of recent trials have indicated that the technological capability for remote ship operations is emerging, if not already available,[48] but it remains unsettled whether the existing legal framework permits remote operation. This question is not strictly about automation and, in that sense, is detached from the categorization made in sections 3.1-3.4 above. However, remote operation is closely linked to the level of on board manning, that is, the vertical axis in Figure 1. For some of the automation scenarios, remote operation is a necessary precondition, while for others it remains a tool that may or may not be put in place. Figure 4 below seeks to illustrate the role of remote operation in the different automation scenarios.

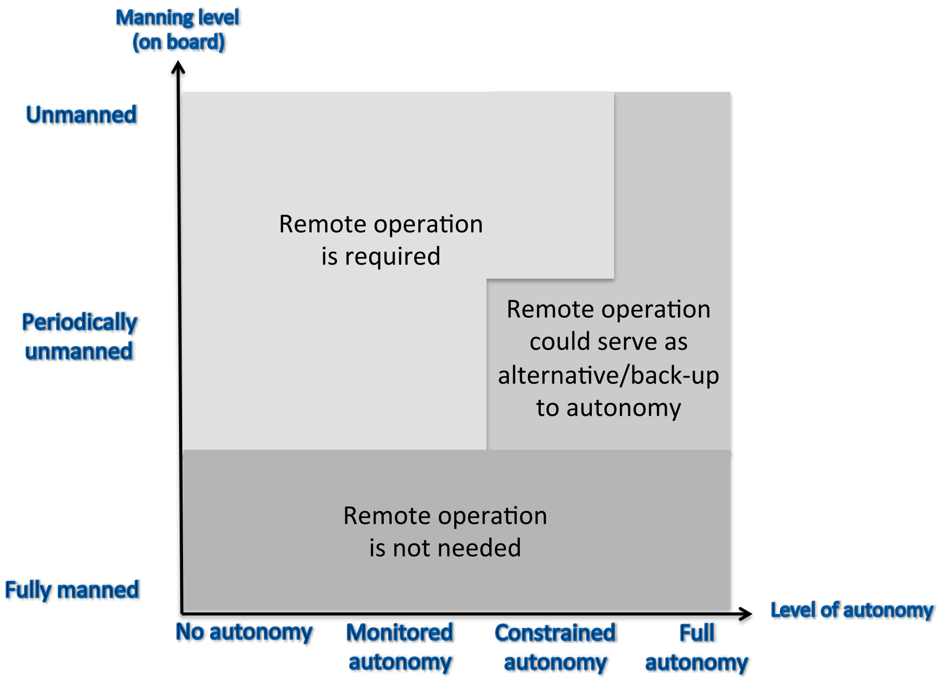

Figure 4: The role of remote operation in different automation scenarios

[47] See e.g. the conditions for operating sole lookout in daylight in STCW Section A-VIII/2, Part 3-1, para. 15, which includes factors such as traffic density, the proximity of dangers to navigation and the availability of immediate assistance by other crew members.

[48] See e.g. www.rolls-royce.com/media/our-stories/press-releases/2017/20-06-2017-rr-demonstrates-worlds-first-remotely-operated-commercial-vessel.aspx (the *Svitzer Hermod*) and www.wartsila.com/media/news/01-09-2017-wartsila-successfully-tests-remote-control-ship-operating-capability (the *Highland Chieftain*).

The physical location of the crew is not usually addressed in the existing IMO conventions. Some of the key functions, including navigational decisions and communications requirements, can therefore be performed remotely without too much direct conflict with existing rules, provided that technical performance is equivalent.

The most important provisions on manning are to be found in SOLAS Regulation V/14 and the associated guidelines on safe manning (IMO Resolution A.1047(27)). Under this regime, decisions on ships' manning are left to the flag state administration. Once the administration is satisfied that the number and qualifications of the crew is adequate for the ship in question, usually assessed on the basis of an estimate and justification proposed by the ship's owner/operator, it will issue a safe manning document for the ship.

In terms of substance, Regulation V/14 essentially only requires that "from the point of view of the safety of life at sea, all ships shall be sufficiently and efficiently manned." The associated guidelines are more detailed and mention a broader range of objectives, including ship security, safety of cargo and environmental protection, but they are not legally binding and are generally formulated by means of goals to be achieved, which opens the door for both remote operation and autonomous solutions.

It is, accordingly, difficult to find a provision in the guidelines that would be directly violated by a decision by a national administration accepting that the functions required to ensure safe operation could be performed from other places than from the ship itself. 'Manned' is not necessarily the same as 'attended' and land-based crews might very well be able to perform many of the operational functions remotely while shore-based maintenance staff could undertake the required maintenance and service work. Indeed the guidelines on safe manning specifically provide that the technical equipment and level of automation are to be taken into consideration when deciding on manning levels.[49] Nor would such a decision by a flag state necessarily conflict with the purpose underlying the safe manning rules, which is to ensure the safety of the ship and its surroundings. It is not excluded that the operation of the ship might actually become safer if more functions are transferred to shore, as electronic lookouts might detect more than humans and new types of equipment, redundancy systems etc. are installed on board.

The main exception to the function-oriented focus for bridge crew requirements is Part VIII of the STCW Convention and the related Code which represent the most direct legal hurdle for remote operations, even on a temporal or periodical basis.

The responsibilities for safe watchkeeping involve several parties, including the company, the master, the chief engineer officers and the whole watchkeeping personnel, whose responsibility it is to ensure "that a safe continuous watch or watches appropriate to the prevailing and conditions are maintained on all

[49] Guidelines, Annex 2, paras. 1.1.3 and 1.1.4.

seagoing ships at all times". This, according to Regulation VIII/2(2)(1), includes 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."[50]

The more detailed requirements are laid down in the STCW Code, Part A of which is mandatory. Chapter VIII of Part A, entitled "Standards regarding watchkeeping", includes a number of the provisions that pose challenges for unmanned operations. For example, Part 4, para. 10, addressing watchkeeping at sea, stipulates 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".[51] In addition, para. 24 provides that "the officer in charge of the navigational watch shall ... in no circumstances leave the bridge until properly relieved". Similar principles are established for the engineering and radio watches, though the provisions on radio watch has no similar presence requirements and can therefore be more easily undertaken remotely.[52]

The requirements cannot be met if the manning of the bridge (or a directly associated location) is relocated, even on a temporary basis. It is unconditional in nature and - unless a very extensive interpretation of terms such as 'bridge' and 'bridge control room' is adopted[53] - offers very limited scope for exemptions or flexibility in compliance.

Under the safe manning resolution, referred to in SOLAS Regulation V/14, the very first principle to be ensured is the capability to "maintain safe navigational, engineering and radio watches in accordance with regulation VIII/2 of the 1978 STCW Convention".[54] It is therefore hardly possible to use any flexibility provided for in the safe manning guidelines to by-pass the physical presence requirements of the STCW regime and this also follows from the stronger legal status of the STCW Code as compared to the safe manning resolution.

However, in relation to lookout duties, there are a number of references to, and duplications of, Rule 5 in COLREGs.[55] In this context, it must be assumed that if a certain kind of lookout is accepted under the COLREGs/SOLAS regime (such as the acceptance of technical aids instead of hearing, as discussed in section 3.3 above), it will also be lawful under the STCW.

[50] Emphasis added. A similar requirement for physical presence for officers in charge of the engine watch in the machinery space laid down in STCW Regulation VIII/2(2)(3) is qualified by the words "when required".
[51] STCW Code Part A, para. 23(2).
[52] STCW Code, para. A, paras 86-89. Reference is also made to SOLAS and the Radio Regulations.
[53] These terms are not defined in STCW or SOLAS. Note also the tight conditions for leaving for the chart room in para 32.
[54] IMO Resolution A.1047(27), para. 3.1.1. See also para 1.2 of the associated guidelines for determination of minimum safe manning.
[55] First part of Code Part 3-1.

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,[56] the Convention offers no flexibility for flag states to adopt equivalent solutions when it comes to watchkeeping. The only applicable exemption is that provided in Regulation I/13 on the conduct of trials.

This possibility could provide a structure for trials with respect to unmanned bridge operations, presuming that guidelines are adopted by the IMO for the purpose. On the other hand, the regulation is complex and includes a number of conditions which do not fit the purpose of trials intended to alter manning principles on a more permanent basis.[57] Moreover, para. 7 of Regulation I/13 offers other states an option to object to the trials and indirectly offers them an opportunity not to permit ships participating in the trial to "engage in a trial while navigating in waters" of objecting coastal States. This contrasts with the freedom of navigation that all ships have in the EEZ of other states and with the right of innocent passage in other states territorial seas that normally applies to ships performing trials under IMO conventions. The provision could prove a challenge for the integration of (periodically) unmanned ships into the regulatory framework, which further underscores why Regulation I/13 may not be ideal for introducing potentially controversial new features to the crewing of ships on a permanent basis.

The only remaining possibility to evade the legal conflict referred to above appears to be a reliance on the choice of words in the article outlining the general scope of application of the STCW Convention. According to its Article III, the Convention applies to "seafarers *serving on board* seagoing ships entitled to fly the flag of a Party" (emphasis added). As unmanned ships have no seafarers serving on board, it could be argued that the Convention finds no application for unmanned operations and that therefore the watchkeeping provisions discussed above do not apply.[58]

This argumentation does not apply to ships that are only partly or periodically unmanned. Even for completely unmanned ones, making such a sharp distinction between on-board and land-based individuals performing functions regulated under the convention seems difficult to reconcile with the overall aim of the convention.[59] Nor would an exclusion of automated bridge functions from the scope of the STCW serve the interests of automation itself as it would counter the aim of incorporating automated ships into the existing maritime environment, including its regulatory framework. Excluding automated watchkeeping from applicable international requirements would raise uncertainty regarding which

[56] See note 37 above.
[57] 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 of time. Nevertheless, para. 8 admits the possibility of indefinite application, subject to a number of strict conditions, including approval by the MSC.
[58] See R. Veal, M. Tsimplis, note 38 above, at pp. 322, 328.
[59] According to the first paragraph of the preamble, the Convention's objective is to "promote safety of life and property at sea and the protection of the marine environment by establishing in common agreement international standards of training, certification and watchkeeping for seafarers".

rules apply to those aspects of watchkeeping that fall outside the STCW. This would promote national solutions and thereby work against the aim of promoting harmonization of international laws in this area.

In conclusion, even if the main part of the IMO rules appear to accept a degree of flexibility for remote operation,[60] the physical presence requirements in the watchkeeping part of the STCW pose a very direct legal obstacle for unmanned shipping and remote bridge operations, even on a temporary basis. Thses obstacles cannot easily be circumvented by the use of exemptions, purposive interpretations or in any other way. In order to overcome this legal hurdle, the provisions will probably have to be modified through amendments. Apart from this, remote control, even if only temporarily employed, triggers a need to address a whole series of associated matters, such as general conditions for utilization, standards for lookout arrangements, requirements on technology, procedures for dealing with communication failures, cyber threats etc. All these need to be met before flag states can confidently accept this type of manning as equivalent in terms of safety.

A different question is whether the IMO should also adopt standards for shore-based control centres and their operation. While the IMO has traditionally avoided regulating shore-based matters, some aspects of shore-control are so closely connected with the safety of ships at sea that it is difficult to see how certain standards in this area could be avoided.[61]

3.6 Technical aspects of the regulatory challenge

Based on some preliminary studies that have already been undertaken, a substantive review of the whole range of IMO conventions is not likely to reveal many direct conflicts or 'show-stoppers' for the introduction of autonomous ships. The watchkeeping rules as currently drafted in the STCW Convention and Code place direct limitations on any efforts to reduce the physical presence of watchkeeping staff on the bridge and elsewhere on the ship, while certain rules in the COLREGs presume human involvement in decision-making and are therefore arguably incompatible with fully autonomous navigation systems. Apart from this, conflicts - in the narrow sense of incompatible provisions that unmanned or autonomous ships would necessarily violate - seem to be few.

Even if most existing rules do not specifically prohibit autonomous or remote operations one should not conclude that autonomous ships can be accommodated into the existing legal framework without further regulatory

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[60] It should be noted though, that even if many of the existing IMO rules do not strictly require the on-board presence of an officer of the navigational watch, provided it is technically feasible to operate all bridge equipment remotely, some of the requirements nevertheless presume the availability of deck crew. For example, the requirement that the officer shall station a person to manually steer the ship to deal with hazardous situations (Code A, para. 35), or ensure periodical inspection rounds during a navigational watch while at anchor (Code A para. 51(4)) can only be complied with if there are some persons physically on board.

[61] Cf the discussions on maritime cyber security, which has resulted in two IMO publications in 2017: the Guidelines on maritime cyber risk management (IMO Doc. MSC-FAL.1/Circ.3) and the Maritime Cyber Risk Management in Safety Management Systems (IMO Resolution MSC.428(98)).

action. In many - if not all - cases, the absence of specific direction on autonomous or remote operations in the IMO conventions may be explained by the circumstance that such operations were not realistic at the time the conventions were drafted. The core of all three conventions considered here were agreed in the 1970's and their drafters never had to deal with the prospect of unmanned or remotely operated ships or bridges. In developing these rules it has been taken for granted that ships are manned and that the functions, as drafted, will be performed by crew members on board the ship. This may have legal implications, too, as far-reaching legal conclusions based on the absence of conflicting requirements could be excluded by the rules of treaty interpretation.[62]

Nevertheless, the absence of an express prohibition of remote performance of functions bears legal significance, since without a prohibition it is easier - in formal terms - to authorize a new practice. For example, an endorsement by IMO member states of the principle that crew functions may be performed away from the ship itself, including from shore-based centres, could clarify the legal situation even if adopted in the form of a non-binding recommendation/circular. Basic principles on human oversight of operations could similarly clarify the acceptable level of autonomy for individual bridge functions. While the recommendations as such are non-binding, they could be considered as a subsequent agreement or practice between the parties under Article 31(3) of the Vienna Convention on the Law of Treaties, and, through that, bear significance for the interpretation of (several) IMO Conventions.

Even a non-binding express endorsement by the IMO membership could thus go a long way towards dispersing the legal uncertainties that are currently associated with the automation of ship operations and would, in particular, open the prospect that flag states could take into account remote or automated operations when considering the safe manning of individual ships.

However, even if the direct regulatory conflicts appear to be few, autonomous or remotely operated ships will no doubt give rise to many kinds of tension with the existing IMO requirements that cannot be resolved by recommendations alone. For example, unmanned ships raise a number of questions with respect to the duties of the master, requirements on maintenance, documentation and pilotage,[63] while many design, access and life-saving requirements will lose their significance if there are no humans on board.

Even such inconsistencies between the new rules and the existing ones need not be carried out through detailed amendments of each provision. They could be addressed in the new instrument, provided the parties are the same, i.e. if the measures were introduced as a new chapter in a convention that is already

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[62] Under Art 31(1) of the Vienna Convention on the Law of Treaties, the main principle of treaty interpretation is that "a treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose."
[63] See Carey and Veal & Tsimplis, note 38 above.

widely ratified, such as SOLAS.[64] As an alternative, priority could also be explicitly established for the new rules through more generic amendments to the existing conventions.[65]

3.7 The role of UNCLOS (can the IMO decide as it wishes?)

A final question to be briefly touched upon is whether the IMO has a mandate to introduce this type of regulatory changes at all. The role of the 1982 UN Convention on the Law of the Sea (UNCLOS) has been identified as a potential limitation of the IMO's authority in this respect.[66]

Assuming that highly automated ships will be considered to be 'ships' or 'vessels' within the meaning of the UNCLOS,[67] the convention's detailed rules with respect to states' rights and obligations in their capacity as flag, coastal and port states apply to such ships as well.

Autonomous shipping operations could raise particular compatibility issues with UNCLOS Article 94, which obliges every flag state to effectively exercise its jurisdiction and control over their ships. This includes taking 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". The wording could be seen as preventing the introduction of fully autonomous ships,[68] but has less impact on remotely operated ships and, even less so, on periodically unmanned ships.

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[64] It is not legally problematic to grant explicit priority for later and more specialized rules for (partly) autonomous ships in the instrument itself, provided that the parties are the same. The *lex posterior* maxim is specifically acknowledged in Art. 30(3) of the Vienna Convention on the Law of Treaties. While there is no similar legislative support for the *lex specialis* maxim in public international law, it is widely acknowledged in judicial practice. See e.g. D. N. Banaszewska, 'Lex specialis', in *Max Planck Encyclopedia of Public International Law [MPEPIL]*

[65] Under Art 30(2) of the Vienna Convention, "when a treaty specifies that it is subject to, or that it is not to be considered as incompatible with, an earlier or later treaty, the provisions of that other treaty prevail."

[66] See e.g. IMO Doc. MSC.99/5/1 submitted by the International Federation of Ship Masters' Associations and the International Transport Federation.

[67] These terms are not defined in UNCLOS, but it follows from the nature of the activities carried out by ships intended here that they probably should be regarded as vessels/ships by virtue of their size, features and functions. Neither international conventions nor national rules defining the term 'ship' include references to crewing. See also Veal & Ringbom, note 39 above, p. 102, arguing that "it would seem unjustified that two ships, one manned and the other unmanned, doing similar tasks involving similar dangers would not be subject to the same rules, which have been designed to address those dangers."

[68] UNCLOS Art. 94(4)(b). The Danish study referred to in note 9 above, at p. 23, has highlighted this in relation to fully autonomous operations and has argued that an amendment of UNCLOS would be necessary before the IMO could proceed regulating the matter. If that were so, the regulatory reform would in reality be very close to be stalled. While UNCLOS does include some provisions on its amendment (Arts. 312, 313), they are excessively demanding and unlikely to be of use in practice. The reluctance to make use of these provisions is also illustrated by the fact that they have never been used, while, in contrast, the option of negotiating an 'implementing agreement' to UNCLOS has already been approved three times. The latter option, however, is unlikely to be suitable for present purposes, as the navigational rights feature in a very large

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".[69] UNCLOS, in other words, deflects the need to formulate the more precise obligations of flag states by referring to an abstract, and continuously changing set of international rules to be developed elsewhere (notably at IMO). 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.[70]

It is therefore submitted that the IMO can regulate the question of autonomous ships in its entirety, even if it is gives rise to tension with the wording of para. 4 of UNCLOS Article 94. The wording of UNCLOS, as a framework convention with 'constitutional' objectives, should not be construed as preventing the introduction of new technologies for shipping, if the international maritime community so desires. Yet, at least as regards entirely crewless ships, legality under Article 94 presupposes that the matter is specifically endorsed by the IMO and subject to more detailed global regulation. The IMO's contribution in this field is therefore essential for enabling the development.

4. Concluding observations

Scoping exercise

This article has sought to illustrate the complexity and number of different elements involved in the regulation of autonomous ships. Only some of those elements are currently covered in the regulatory scoping exercise that has recently commenced at the IMO, focusing on the regulatory challenges that autonomous ships will meet in existing IMO conventions.[71]

A broad-brushed review of hundreds of individual provisions is unlikely to significantly increase knowledge about the nature of the regulatory challenges ahead, even if a suitable methodology could be established for the purpose. A review of the compatibility of autonomous ships with specific provisions in existing conventions will of necessity have to be very generic until a more detailed nature and content of the new rules is known. It has also been noted above that the lack of attention to automation when the existing rules were drafted cautions against a strong reliance on their wording when assessing the lawfulness of the new development. Moreover, treaty law offers smoother ways to authorize the new development than a provision-by-provision amendment of each rule that is or could be problematic.

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number of provisions on flag, coastal and port state jurisdiction and there appears to be no policy demand for the amendment of any of these provisions.

[69] UNCLOS Art. 94(5)

[70] Note also the CMI questionnaire MSC.99/INF.8, where 10 out of 12 responding states' maritime law associations took a similar view on UNCLOS and considered that the IMO has the formal competence to regulate unmanned ships.

[71] But note the fairly broad terms of reference of the IMO working group quoted at n. 3 above.

Apart from such general considerations, the selected scope of the exercise places some important limits on what can be achieved. Many of the key issues that determine the legality of unmanned and/or autonomous ships, such as automated lookout functions or machine-based decision-making, do not feature in existing conventions at all, and will not thus be addressed in an exercise which only focuses on existing provisions.

Moreover, the exercise in its current format does not include *grades* of autonomy or a *partial* removal of crews within its scope, but only covers a binary either-or option. The review above has demonstrated how in many cases both the nature of the legal challenge and the measures required to resolve it differ quite widely depending on the level of manning and automation involved. The precise allocation varies from one instrument and function to another, but in most cases a partially unmanned bridge (or ship) is clearly easier to accommodate in the current legal framework than a fully unmanned counterpart, while the degree of human oversight similarly determines the level of challenge with autonomy. These "half-way" solutions are also likely to be more attractive for ship operators to adopt in the shorter term and hence the most urgent ones to resolve.

Nevertheless, the review has also shown that many of the key legal issues will arise at a very early stage of development. The legal challenges linked to autonomy concern the periods in which the system operates independently, no matter how brief or basic those operations might be. The legal issues linked to remote operations similarly arise as soon as a remote controller assumes the watchkeeping tasks of a person who has traditionally been physically on the bridge.

A thorough, broadly-based and wide-ranging desk-top exercise like the one currently undertaken by the IMO could provide a useful opportunity to address the full complexity of matters linked to increased autonomy of ships and the available solutions. Over-simplifying the task at this stage risk setbacks later in the process. A comprehensive review of the elements needed for a robust regulatory framework, including a review of the legislative options available to achieve that, would seem more helpful at this stage, even if it will necessarily signify some further complications regarding the exercise.

Regulatory challenge
Should the IMO decide to proceed with the task beyond regulatory scoping, a series of issues would have to be dealt with which go beyond provisions in the existing conventions. The review of the four categories of rules required for automating bridge functions highlighted both the uniqueness and the width of the regulatory challenge facing the IMO. While regulation of automation is by no means a new topic for the organization, available precedents are not comparable to the issues raised by this development and thus of limited assistance for guiding the organization on how to proceed. The novelty of the subject represents an argument in favour of developing a new instrument to specifically address the various aspects of highly automated and autonomous ships.

The assumption that ships that are *entirely* unmanned or *fully* autonomous are not likely to be introduced in the short or even medium term is no reason to postpone the exercise. A regulatory framework will be needed even in the case of partially unmanned and/or remotely controlled ships.

In the shorter term, lighter non-regulatory solutions could serve to provide clarity to current legal uncertainties, for example regarding the conditions under which ship functions may be carried out remotely or technology could replace the human lookout. In this respect, it is of legal significance that relatively few of the existing IMO requirements pose direct legal conflicts that would rule out the development towards autonomy. While conflicts need to be addressed by convention amendments, lighter tensions can be addressed by means of interpretations or common understandings which can be achieved through less formal measures.

In the longer term, the many novel elements entailed in that autonomous ships argue in favour of a new regulatory instrument, or mandatory code, which is specifically dedicated to this matter. The main challenge in this work lies in the breadth of the new rules and standards that need to be developed. The relevant technical standards for all four categories of automation outlined in section 3 need to be addressed and the available precedents serving as models are few. Technical standards for automated situational awareness, remote operation of ships and system-based decision-making need to be developed from scratch, along with more generic requirements regarding redundancy, cyber security, enforcement, certification training etc.

In terms of regulatory technique, the more recent development within the IMO towards goal-based standards (GBS) may ease the task considerably. Under GBS, the statutory rules only outline the objectives to be achieved and certain functional requirements, as well as a verification process, but leave the detailed means of achieving those objectives and requirements to flag states, classification societies, and ship designers and builders.[72] GBS accordingly reduce the level of prescription and introduce flexibility with respect to how the goals are to be achieved. Even if the practical experience so far with GBS has focused on technical standards,[73] there is no formal limitation to that effect and the application of the principle to any kind of standards is emphasized by the organization.[74] The role of GBS as a regulatory technique for introducing further automation in shipping has accordingly been promoted.[75]

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[72] www.imo.org/en/OurWork/Safety/SafetyTopics/Pages/Goal-BasedStandards.aspx

[73] See e.g. SOLAS regulation II-1/3-10 on Goal-based ship construction standards for bulk carriers and oil tankers and the associated Resolution MSC.287(87) from 2012.

[74] *Ibid.*, see also IMO Circular MSC.1/Circ. 1394 (Generic Guidelines for Developing IMO Goal-Based Standards).

[75] The Polar Code, adopted in 2014 and 2015, could represent an interesting (albeit much less complex) precedent, partly in terms of substance in view of its dual approach towards goal-based and prescriptive standards and its holistic risk-based approach, but also as regards the form, given that the Code amended several key IMO conventions. See also M. Bergström, S. Hirdaris, A. Lappalainen, O.A. Valdez Banda, P. Kujala & O-V. Sormunen, 'Towards the Unmanned Ship Code', Proceedings of the 13th International Marine Design Conference (IMDC 2018), June 10-14, 2018, Helsinki, Finland.

In the absence of any regulatory guidance by the IMO on these matters, interpretation of the international requirements will be left to individual (flag) states. It may well be that states have rather different interpretations on the meaning of terms discussed above and on the available latitude of discretion, which in itself is a justification for pursuing international harmonization in this area without delay. Another reason is the practical need for regulating autonomous shipping. It has been highlighted above that both autonomy and manning represent sliding scales and that on both topics the need for a new legal framework arises at a very early stage of development. Even if fully autonomous ships plying the oceans without any human involvement may remain a distant vision, the need to clarify the legal framework for periodically unmanned ships, or ships that are partly operated by autonomous navigating systems, already exists.