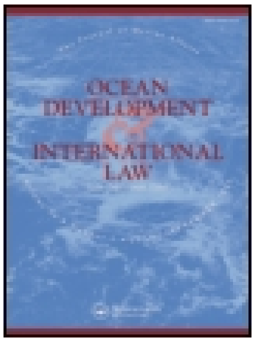

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Regulating Autonomous Ships—Concepts, Challenges and Precedents

Henrik Ringbom

Scandinavian Institute of Maritime Law, University of Oslo, Oslo, Norway

ABSTRACT

The article seeks to contribute to the development of a conceptual framework for the ongoing regulatory discussions on autonomous ships at the International Maritime Organization (IMO). It elaborates on the distinction between the level of autonomy and the level of manning and highlights the sliding scale that features in both. 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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Autonomous ships; IMO; MASS; periodically unmanned ships; remotely operated ships

Introduction

The international debate on autonomous and unmanned ships, which has gathered significant momentum in the past few years, has recently reached 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 to assess the regulatory challenge that various degrees of autonomous shipping pose for each provision in the selected instrument.[4]

CONTACT Henrik Ringbom h.m.ringbom@jus.uio.no Professor II, Scandinavian Institute of Maritime Law, Faculty of Law, University of Oslo, Adjunct Professor (Docent) in Maritime Law and the Law of the Sea, Åbo Akademi University, Turku/Åbo, Finland. Member of the CMI observer delegation to the IMO in the on-going discussions on autonomous ships. The research leading to this chapter has been undertaken as part of the D4V research project, sponsored by Business Finland and coordinated by DIMECC, for the Faculty of Law at the University of Turku. The author wishes to thank Felix Collin and Martin Bergström for their helpful comments on earlier drafts. Any views expressed in the article are solely those of the author.
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In a second phase, potential regulatory solutions to address the challenges identified will be analyzed.[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 process, 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 further complicating the exercise, it is important to seek to clarify the meaning of key concepts and relationship from the outset.

With this goal in mind, the present article seeks to clarify some of the key features and terminology related to automation in shipping and to 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 gray-scales involved, is outlined in the 'Conceptual Framework' section below.

The regulatory challenge is assessed in more concrete terms in the third section, through an examination of specific legal hurdles and past practice of the IMO in regulating automation in shipping, with a particular focus on bridge operations.[6] This 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," discusses the relationship between different aspects of automation, and evaluates past precedents as against existing challenges. Crew functions performed remotely, from a location outside the ship itself, are discussed as a fourth category. The examples are drawn from three main IMO conventions that are deemed to be of particular relevance: the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention)[7]; the International Regulations for the Preventing of Collisions at Sea, 1972 (COLREGs)[8]; and the International Convention for the Safety of Life at Sea, 1974 (SOLAS).[9]

The final section returns to the challenge facing the IMO in this area, in the ongoing scoping exercise and in the longer term, should it decide to proceed with regulatory reform in this field. Some thoughts are offered as to how 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 dominate the regulation of autonomous ships in the future.

Conceptual Framework

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 as a development in relation to the level of autonomy (independence) of operational functions.[10] In addition, a key feature of unmanned shipping is the increased importance of tasks executed remotely, away from the ship itself. All three elements are crucial aspects in the development of autonomous shipping and they are closely interlinked and interdependent. Nevertheless, they are separate issues that are often confused in the current regulatory discussions.[11]

The legal questions and challenges linked to autonomous shipping, as well as the solutions needed to resolve them, will differ depending on what choices are made in relation to manning, crew location, and autonomy level. The level of 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 legal questions different 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 whether the ship's equipment is expected to resolve all situations autonomously.

Each requirement or function needs to be assessed separately. 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, must be performed by on-board crew. To the extent that bridge functions can technically be performed remotely, including such key functions as lookout and manoeuvring, the removal of those functions from the ship to shore is likely to be a key aspect in the development of 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 acceptable level of autonomy 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 to distinguish the key issues involved.[12] In Figure 1, 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. The figure highlights the sliding (nonbinary) nature of both axes, which are discussed in more detail in the following. Generally, legal and policy controversy tends to increase the further up the arrow one moves in the graph, but this development is not linear.

Finally, it should be noted that the temporal scales 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, and so on.

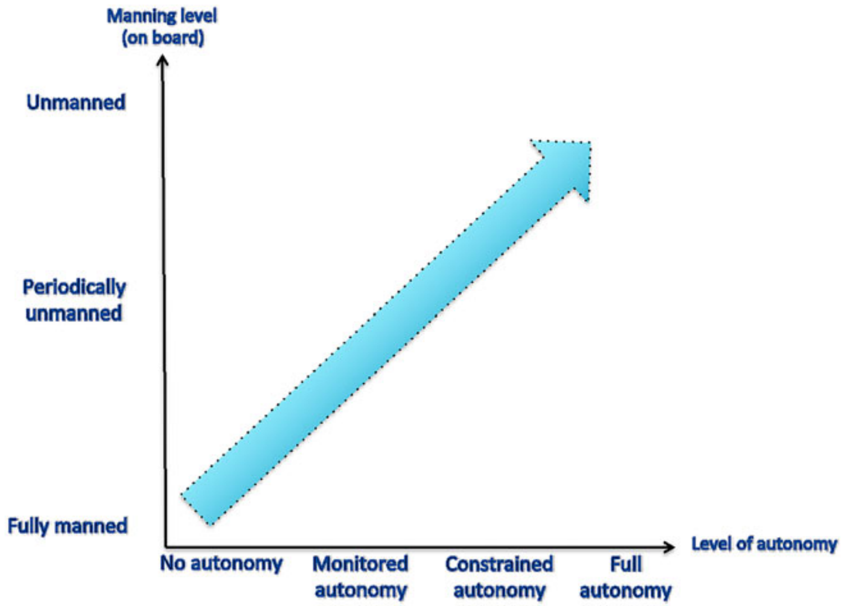

Figure 1. Separating the two key aspects of ship automation.

A solid regulatory framework for autonomous shipping operations should be able to deal with such variations and should not be limited to a specified level of manning or autonomy. It will probably have to be introduced step-by-step in view of the many elements involved and the developments in technological availability, commercial demand, and political acceptability. The discussion that follows focuses specifically on the legal challenges linked to the automation of bridge functions and navigational decisions, such as collision avoidance.

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 for watchkeeping and other duties on board ships that are currently required by international rules. As long as this level of manning does not change and the crew's role and responsibilities remain unchanged, 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.[13] 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 in the following), 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 creates a number of legal hurdles in light of the existing international rules, notably the requirements on watchkeeping and on the safe manning of ships.[14]

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 control centre or autonomously, or through a combination of these.[15] In contrast to the completely unmanned bridge, this option entails that some competent crew members are retained on board who can react to alerts and assume control of the ship's operations when needed.[16]

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 the situational awareness function to automated systems. The ship would then hold a given course and could alert the crew to various dangers through alarms based on predetermined parameters. In a somewhat more developed variant, the system would autonomously perform preprogrammed steering maneuvers to avoid close contact with other ships or shallow waters, but would alert crew members to assume control in situations where those parameters could not be met, before a dangerous situation arises. At the other end of the spectrum for periodically unmanned bridges, the ship would be operated autonomously or remotely for most of the time with a single officer/master on board to 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, during 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.[17] A completely unmanned bridge, by contrast, needs more regulatory attention to redundancy functions and operation in case the communication links to the control center 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,[18] and because any type of unmanned operation of ships, even in a light and temporary format, raises legal issues that the current legal framework does not properly address.

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 issue encompasses a wide range of situations from full human involvement in the operations to fully autonomous systems that operate without any human intervention. Increasing the autonomy is therefore concerned with removing human involvement in a much more fundamental sense than a mere shift in the location of the persons involved. Autonomy in a navigational context signifies that human decision making on board is replaced by information technology (IT)-based solutions on the basis of preprogrammed algorithms and/or computer-based learning. The more autonomous the function is, the greater is the departure from traditional navigational practices, and inevitably legal issues start to surface. For example, the collision avoidance rules in the COLREGs presume that a human is in the decision-making loop, as they refer to the "good seamanship" of the individuals in charge of navigation and specify that navigational decisions are not supposed to deviate from the "ordinary practice of seamen."[19] 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.[20] 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 scenario, the autonomous system offers decision support for the crew, but involves no alteration of their role or responsibilities. In the "constrained autonomy" option, 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 control over navigational decisions, rather than the level of sophistication of the system. Hence the most important point, in terms of authorising autonomous operations, but also with respect to assessing responsibility and liability, is the moment at which "monitored autonomy" turns into "constrained autonomy." It is at this point that the system is partially authorized 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 from a legal standpoint.

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 well change during a single voyage, depending on the trading area, the traffic conditions, and so on. A relevant legal question in this regard is thus how the level of autonomy of a ship 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?

Links Between the Elements

The preceding discussion has emphasized the importance of separating the different elements of automation. However, it is clear that the elements of automation 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 that 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 contact with the shore-based control center is lost. Communication between the ship and shore may also be limited by reduced bandwidth capacity, radio disturbances, and other foreseeable risks. For this reason, a certain degree of autonomy 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.

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 are 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 the level of autonomy. In the former case, the key legal hurdles flow from 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 preceding that such legal hurdles may arise quite quickly when moving along the arrow in Figure 1. When moving upward in the graph by reducing the on-board manning, the first legal problems will arise as soon as the officer on watch leaves the bridge or associated location. The problems created by the 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 members from a remote location is not settled in any of the existing legal instruments.

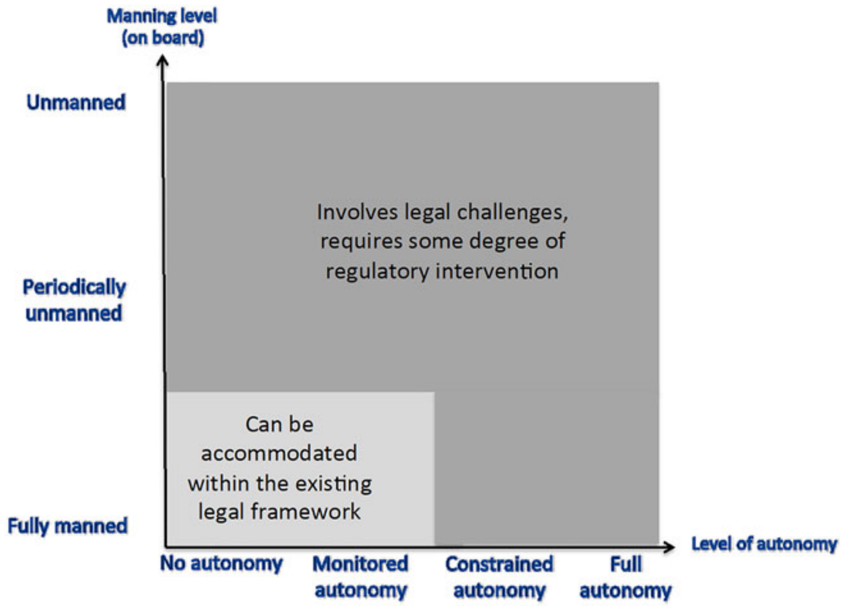

Figure 2. Nature of the legal challenge.

Similarly, a ship can be in an autonomous mode of operation even with comparatively modest levels of autonomy, that is, 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 autopilot that operates to actively avoid close contact with other ships and alerts the crew in cases where this cannot be accomplished, 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 preceding observations may be illustrated in Figure 2 by adding a rough categorization of the legal challenge involved to the graph used in Figure 1.

The Degrees of Automation at IMO

In the early phases of the IMO discussions on ship autonomy,[21] the focus was exclusively placed on entirely unmanned ships. This permitted a simple autonomy grading between remote control and full autonomy, that is, at the highest level of the vertical axis in Figure 1. Since then, the debate has broadened and various degrees and modes of manning are now being considered. The inclusion 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 toward completely unmanned ships, and likely also 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.

To date, the distinction between the different aspects of automation has not received much attention in international discussions. The IMO's working 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.[22]

The indistinct references to levels of autonomy (1 and 4) and manning (2 and 3) in the four categories risk generating confusion in future regulatory debates.[23] In addition, and perhaps more importantly, the working group's desire to keep the number of variables low has resulted in the omission of any grading of the levels on the axes. Many issues of crucial relevance for identifying the scope of the challenge and the available solutions, and of critical importance from a commercial perspective, such as periodically unmanned bridges or partially autonomous functions, are therefore not included in the exercise as currently defined.

Nature of the Legal Challenge facing the IMO—Categories and Precedents

Introduction

To establish more concretely the 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, that is, 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.[24] However, all three categories of functions need to be addressed to enable a development towards autonomous ships.

Autonomy also exists at different levels of technical sophistication. While less advanced autonomous systems make their navigational decisions based on algorithms and software that have been preprogrammed (by humans) for specific purposes, 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.

Figure 3 represents an effort to schematically illustrate the relationship between the categories of automation discussed in the following.

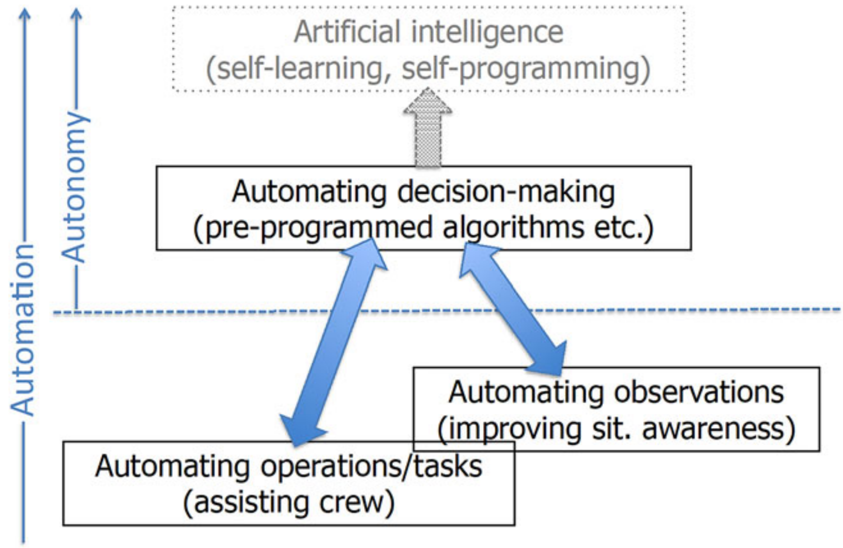

Figure 3. Different categories of automation required for automating bridge functions.

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 highlighted by the fact that existing precedents at the IMO offer relevant guidance for only two of the four categories. For the remaining two, the organization is entering uncharted territory.

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.[25]

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.[26] 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 maneuvered much more accurately than humans could ever do manually. In terms of standards, DP also represents a high level of sophistication, by defining three different levels of automation and including requirements related to redundancy, crew training, and governmental supervision and control.[27] These existing systems, which are currently regulated by means of nonbinding resolutions only, could be of significant interest as 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 are expected to interfere with the operations at any time should the need arise.[28] 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 attempts to automate operations. The prime example is the ultimately unsuccessful experiment with one-man bridge operations in periods of darkness. This practice did cause some tension with the applicable manning rules, even if it did not affect the responsibility of the officer of the navigational watch.

The overriding principle regarding a lookout for both the COLREGs and the STCW is that a proper lookout shall be kept at all times. In the original STCW Convention from 1978, it was already accepted that a single person could perform the duties linked to watchkeeping, including the lookout, provided certain conditions were met.[29] In the late 1980s, pressure increased to extend the one-man operation further to include the hours 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.[30] The trials were only open to 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 authorized by flag states were undertaken,[31] and a parallel process for amending the STCW Convention to permit solo watchkeeping in periods of darkness was initiated.[32]

Throughout the trials, there was significant resistance to these proposed developments. Countries opposing the development insisted that 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 the COLREGs and STCW.[33] From an early stage, certain states, led by the United States, demanded that ships participating in the experiment 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.[34]

Due to 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.[35] Consequently, the proposed draft amendments to the conventions were also withdrawn. The only remnant of the debate today is the strictly worded provision specifying when flag states may authorize tests deviating from the STCW Convention. This provision, STCW Regulation I/13, is discussed further in the following.

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 facing the automation of operational tasks. As long as automation is simply layered on top of existing rules, without causing tension with them, even far-reaching forms of automation can be accepted. Conversely, if automation involves changes to 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.

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, that is, 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."[36] 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 objective of Part E is to ensure equivalent safety standards to manned machinery spaces, in all sailing conditions.[37]

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.[38]

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.[39] This example is thus located relatively high up 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 from the mid 1960s before finally being introduced into SOLAS in 1988.

Another precedent of more immediate relevance to bridge crews relates to compliance with the lookout requirement in the 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 the 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 the COLREGs Rule 5 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 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 rules, does not necessarily denote a person, but rather the systematic collection of information.[40] If that interpretation is accepted, the threshold for approving a technological replacement for the human lookout becomes considerably lower.

The purpose of the lookout rule is arguably to make sure that whomever controls the ship is aware of the circumstances on and around the ship so as to make informed decisions on actions to avoid collisions and other incidents. The preceding example of a sound reception system for enclosed bridges illustrates that a strictly literal interpretation of the "sight and hearing" requirement 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 the 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 the COLREGs and the nature of collision regulation (usually 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, and 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.[41] Neither the COLREGs nor the watchkeeping parts of the STCW include this option.

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, that is, 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 preprogrammed software that performs navigational decisions to avoid collisions with other ships and objects in accordance with the COLREGs. By contrast, a ship that merely navigates along a manually preprogrammed 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, though not all of them appear in the form of a direct conflict with existing rules.[42]

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 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 created by even relatively modest levels of autonomy. As was noted in the second section, many issues of principle arise already at comparatively low levels of sophistication within the autonomy spectrum, 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,[43] and accept a broader range of equivalence-based solutions.[44] 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.[45] Most functions in the guidelines that specifically concern bridge crews could be performed by automated systems, provided that the performing technology is available.

The principal hurdle in this regard are the rules that explicitly require human judgement in the navigational decision-making loop. Some key examples are found in the COLREGs. Rule 2, for instance, 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 the COLREGs generally, are neutral with respect to who makes the decision or from what location.[46] 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 the COLREGs, even taking into account the sometimes unpredictable actions of other ships, and the somewhat conditional distribution of rights and obligations in the rules.[47] The references in Rule 2 and Rule 8 to "the ordinary practice of seamen" and "good seamanship," however, introduce less precise 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 preprogram "good seamanship" into an automated navigation program will be fraught with serious difficulties.[48] A key question is therefore to what extent the quoted provisions of the COLREGs prohibit an autonomous, IT-driven collision avoidance system.

Arguably not completely. First, it follows from the text of the COLREGs that the references in question only apply in navigational situations or incidents at a developed stage. For example, by the time the good seamanship requirements become relevant under the COLREGs in a collision situation, 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 having ships end up in a "close quarters" situation in the first place.[49] The more cautiously the system is programmed in terms of values on closest point of approach or in determining alarm parameters and so on, the easier it will be to make the system fit within the wording and spirit of the COLREGs.[50]

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 detect, in good time, any approaching traffic or other object or event. 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 center. The latter case needs to provide solutions for ancillary risks such as loss of or delay in communication and ensure redundancy. 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 issue would seem to strengthen the case for either periodically unmanned bridges with the crew on board, or completely autonomous ship-based systems, over remotely controlled unmanned bridges.

Third, 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. Outlining the specific conditions under which autonomous navigation systems can be used would also reduce tension with the COLREGs.

In conclusion, even if certain COLREGs provisions rely on a human in the decision-making loop, autonomous navigation systems are not entirely excluded by the convention. The matter has not been discussed at the 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 in place to enable human intervention when necessary.[51] However, in view of the many uncertainties associated with the technical limits of autonomous navigation systems, further guidance on the conditions for operating such systems seems necessary.

Relocating Operations (Performing Shipboard 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, that is, whether the tasks of the bridge crew can be accomplished 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,[52] but it is still unclear whether the existing legal framework permits remote operations. This question is not strictly about automation and, in that sense, is distinct from the categorization made in the preceding subsections. 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 seeks to illustrate the role of remote operation in the different automation scenarios

The physical location of the crew is not usually addressed in the existing IMO conventions. Some of the key functions, including navigational decisions and

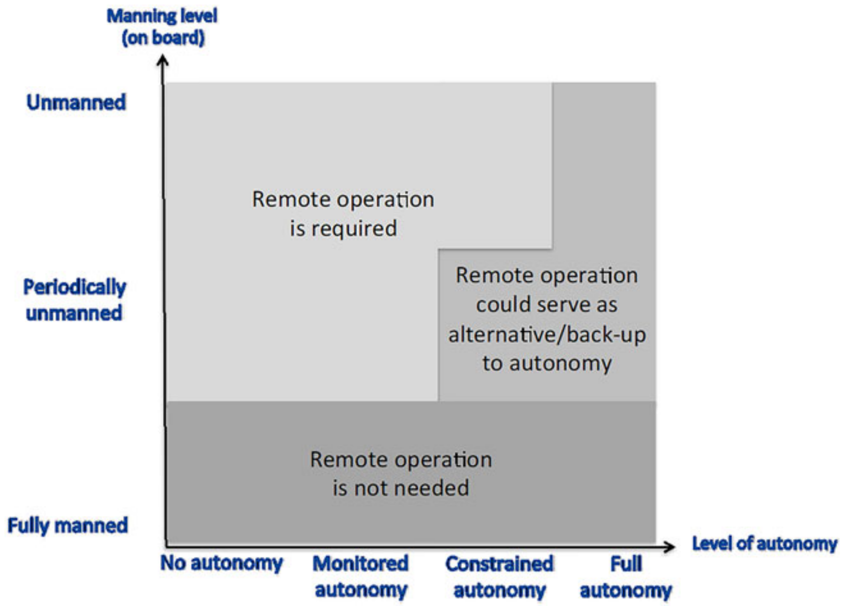

Figure 4. The role of remote operation in different automation scenarios.

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 are 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 can be performed from places other 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.[53] 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 automated, as electronic lookouts may detect more than humans, and redundancy systems and so on would be 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 STCW 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 seagoing ships at all times." This duty, 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."[54]

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 4-1, para. 18, dealing with 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." The first of those factors is that "at no time shall the bridge be left unattended."[55] In addition, under para. 24, "the officer in charge of the navigational watch shall … in no circumstances leave the bridge until properly relieved." Similar rules are established for the engineering watches, while the provisions on radio watch have no similar presence requirements and can therefore be more easily undertaken remotely.[56]

The requirements outlined above cannot be met if the manning of the bridge (or a directly associated location) is relocated, even on a temporary basis. They are unconditional in nature and—unless a very extensive interpretation of terms such as "bridge" and "bridge control room" is adopted[57]—offer very limited scope for exemptions or flexibility in compliance.

Under the guidelines on safe manning, which are referred to in SOLAS Regulation V/14, the most important principle is the capability to "maintain safe navigational, engineering and radio watches in accordance with regulation VIII/2 of the 1978 STCW Convention."[58] It is therefore difficult to rely on the flexibility provided in the safe manning guidelines to bypass the physical presence requirements of the STCW regime, a conclusion reinforced by 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 the COLREGs.[59] 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 the preceding), it will also be lawful under the STCW.

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

This exemption could allow for trials with respect to unmanned bridge operations, presuming that guidelines are adopted by the IMO for the purpose. However, Regulation I/13 is complex and includes a number of conditions difficult to apply to trials intended to alter manning principles on a more permanent basis.[61] Moreover, para. 7 of Regulation I/13 offers states the option of objecting to the trials and indirectly offers them the opportunity of barring ships participating in the trials from doing so "while navigating in [their] waters." This contrasts with the freedom of navigation that all ships enjoy in the exclusive economic çone (EEZ) of other states and with the right of innocent passage in territorial waters that normally applies to ships performing trials under IMO conventions. The provision could thus 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 STCW 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 STCW Convention finds no application for unmanned operations and that therefore the watchkeeping provisions just discussed do not apply.[62]

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.[63] 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 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 rules in this area.

In conclusion, even if most IMO rules appear to accept a degree of flexibility for remote operation,[64] 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. These 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. In addition, 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, and so on. All these issues need to be identified and resolved 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 centers 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 the determination of uniform standards in this area could be avoided.[65]

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.[66] The watchkeeping rules as currently drafted in the STCW Convention and STCW 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 these specific rules, conflicts—in the narrow sense of 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 action. In many—if not all—cases, the absence of specific parameters for autonomous or remote operations in the IMO conventions may be explained by the fact that such operations were not realistic at the time the conventions were drafted. The core elements of all three conventions considered in this paper were agreed in the 1970s and their drafters never had to deal with the prospect of unmanned or remotely operated ships or bridges. In developing the existing rules, it was taken for granted that ships would be manned and that the functions identified would be performed by crew members on board the ship. This historical context may have legal implications, as the ability to draw far-reaching conclusions on the sole basis that no specific provisions preclude them may be excluded by the rules of treaty interpretation.[67]

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 centers, could clarify the legal situation even if adopted in the form of a nonbinding recommendation/circular. Basic principles on human oversight of operations could similarly clarify the acceptable level of autonomy for individual bridge functions. While any such recommendations would be nonbinding, 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, as a result, impact the interpretation of several IMO Conventions, including those discussed in this article.

Therefore even a nonbinding express endorsement by the IMO membership would go a long way toward 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 direct regulatory conflicts appear to be few, autonomous or remotely operated ships will no doubt give rise to many kinds of tension with 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, as well as requirements with regard to maintenance, documentation, and pilotage,[68] while many design, access, and lifesaving requirements will lose their significance if there are no humans on board.

Such inconsistencies between new modes of operation and existing rules do not necessarily have to be resolved through detailed amendments to each relevant provision. The necessary revisions could also be laid out in a separate instrument. Such an instrument would have priority over older rules provided all the parties are the same, that is, if the measures were introduced as a new chapter in a convention that is already widely ratified, such as SOLAS.[69] As an alternative, priority could also be explicitly established for the new rules through more generic amendments to existing conventions.[70]

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 change at all. The role of the 1982 UN Convention on the Law of the Sea (UNCLOS) has been identified as a potential limitation on the IMO's authority in this respect.[71]

Assuming that highly automated ships will be considered to be "ships" or "vessels" within the meaning of the UNCLOS,[72] 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,[73] but has less impact on remotely operated ships and even less so on periodically unmanned ships.

When adopting Article 94 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."[74] UNCLOS, in other words, avoided the need to detail the precise obligations weighing upon flag states by referring to an abstract and continuously changing set of international rules to be developed elsewhere (notably at the IMO). In this way, the convention 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.[75]

It is therefore submitted that the IMO can regulate the question of autonomous ships in its entirety, even if it gives rise to some tension with the wording of paragraph 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 if such developments are to take place.

Concluding Observations

Scoping Exercise

This article has sought to illustrate the complexity and the 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.[76]

A broad-brush 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 the the nature and content of the potential new rules on the topic are known. It is, in other words, difficult to assess the regulatory problems linked to a new development when the details of that development are not known. It has also been noted in the preceding 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 any new development. Moreover, treaty law offers more efficient ways to authorize new developments than a provision-by-provision amendment of each rule that is or could be problematic. Conflicts with potential new rules for MASS could, for example, be addressed by more general priority clauses in the conventions concerned.

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 thus not be addressed in an exercise focused only 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 preceding review has demonstrated how, in many cases, both the nature of the legal challenge and the measures required to resolve it differ quite significantly depending on the level of manning and automation involved. This assessment 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 in relation to autonomy. These "halfway" situations are also likely to be more attractive for ship operators in the shorter term and hence are 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 available solutions. Oversimplifying the task at this stage risks 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 it, would seem more helpful at this stage, even if it will necessarily complicate and lengthen the exercise.

Regulatory Challenge

Should the IMO decide to broaden the current limited regulatory scoping exercise, a series of issues that go beyond the current provisions in existing conventions will have to addressed. The review of the four categories of rules required for automating bridge functions highlighted both the uniqueness and the depth of the regulatory challenge facing the IMO. While regulation of automation is by no means a new topic for the organization, the available precedents are not analogous to the issues raised by the development of MASS and are thus of limited assistance and guidance for the organization. The novelty of the subject represents an argument in favor 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, flexible nonbinding solutions could help resolve some of the legal uncertainties, for example, regarding the conditions under which ship functions may be carried out remotely or when technology can 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 developments in favor of autonomy. While conflicts will need to be addressed by amendments to existing conventions, less significant tensions can be addressed by means of interpretations or common understandings that can be achieved through less formal measures.

In the longer term, the many novel elements that will arise from the operation of autonomous ships argue in favor of a new regulatory instrument, or mandatory code, that is specifically dedicated to this matter. The main challenge will lie 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 the third section need to be addressed and the precedents available to serve 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, cybersecurity, enforcement, certification training, and so on.

In terms of regulatory technique, the more recent trend within the IMO toward 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.[77] 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,[78] there is no formal limitation to that effect and the application of the principle to any kind of standards is emphasized by the organization.[79] The use of GBS as a regulatory technique for introducing further automation in shipping has accordingly been promoted.[80]

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 of the key terms discussed in the preceding and in regard to their level 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 in the preceding 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.

Notes

1. IMO Docs. MSC 98/23, MSC 98/20/2 and MSC 98/20/13.
2. In total, 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 has been set up specifically 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.
6. The focus of the review is a hypothetical large commercial cargo ship engaged in international trade carrying nondangerous 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. 1361 *U.N.T.S.* 190, 1984 *U.K.T.S.* 50, as amended.
8. 1050 *U.N.T.S.* 16, 1977 *U.K.T.S.* 77, as amended.
9. 1184 *U.N.T.S.* 2, 1980 *U.K.T.S.* 46, as amended.
10. 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 and specifically addresses independence in relation to decision making. See further discussion in the following subsections.

11. For example, in the Finnish submission in IMO Doc. MSC 99/5/6, six international efforts to categorize the level of autonomy of ships are listed. Three of them consider remotely operated ships as a distinct category of autonomy. See also the IMO working group's own grading of autonomy presented in a later subsection of this article.
12. See also the Danish Study "Analysis of Regulatory Barriers to the Use of Autonomous Ships," by Ramboll & Core, 2017, attached to IMO Doc. MSC 99/INF.3, at, p. 7.
13. See, e.g., the 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 the STCW Code A, Section VIII/2, para. 8.4, providing that officers in charge of watch duties "shall maintain a proper watch, making the most effective use of all resources available, such as information, installations/equipment and other personnel."
14. These tensions are discussed in more detail in the following.
15. To meet the status of a periodically unmanned ship, 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 where the crew is physically brought in only when the ship approaches shore or a congested sea area.
16. It should also be noted that the distinction between unmanned and periodically unmanned is not straightforward. Although a completely unmanned bridge 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 return to service, the duration of stand-on time, etc., all of which will affect the measures needed to implement the scheme.
17. See also the regulatory solutions established for periodically unmanned machinery spaces referred to in later discussion in this article.
18. Both remotely operated and autonomous operations are currently being explored by equipment manufacturers to cover 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.
19. COLREGs Rule 2 and Rule 8. See further discussion in the following.
20. There is no consensus on this categorization in the maritime context or elsewhere. See, e.g., IMO Doc. MSC 99/5/6 referred to earlier. 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 has been chosen as it is considered that four levels of autonomy suffice to highlight the main legal issues involved.
21. Including in the quasi-totality of the submissions made to MSC 99 referred to in supra note 2.
22. MSC 99/WP.9, Annex 1, para. 4. See also the Danish study referred to in supra note 12.
23. See also R. Veal, "Maritime Surface Ships: Autonomy, Manning and the IMO," *Lloyd's Shipping & Trade Law*, 3 July 2018, available at www.shippingandtradelaw.com/shipping/maritime-autonomous-surface-ships-autonomy-manning-and-the-imo-130728.htm.
24. See also the "Definitions for Autonomous Merchant Ships," issued by the Norwegian Forum for Autonomous Shipping (NFAS), available at 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."
25. 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.
26. Reg. V/19.2.8

27. The original guidelines for vessels with dynamic positioning systems from 1994 (MSC/Circ.645) were replaced by a new set of guidelines for vessels and units with dynamic positioning systems in 2017 (MSC.1/Circ.1580).
28. 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."
29. STCW 1978, Reg. II/1.9. See also Section A-VIII/2, of the STCW Code, para. 16.
30. 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").
31. 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 for 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.
32. IMO Doc. NAV 40/25, Annex 18 (Draft MSC Circular), Annex (Draft Requirements for Solo Watchkeeping during Periods of Darkness). 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.
33. See, e.g., IMO Doc. MSC 59/11/4.
34. See, e.g., IMO Doc. NAV 40/25, Annex 18, para. 6.2.
35. IMO docs. MSC 65/25, paras 9.9–9.19, and 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.
36. Specific requirements for unmanned machinery spaces have subsequently also been included in the STCW Code. See, e.g., note 39.
37. Reg. II-1/46(1). The rules include means for early detection of fires (Reg. 47) and flooding (Reg. 48) in machinery spaces. It is required that the propulsion machinery be 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 also 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 shutdown safety system in case of immediate danger (Reg. 52). Additional requirements apply for passenger ships (Reg. 54).
38. For example, the term "periodically" is not specified in SOLAS, which makes it unclear how long the machinery spaces may be left unattended. Optimally, normal maintenance schedules should fix the limit, rather than formal predetermined 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).
39. See STCW Code A VIII/2, Part 4-2, 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 "the assignment of class notations E0 and ECO is based on the assumptions that: engineering staff can attend the machinery space at short notice" (section 1, para. A 204).
40. See, e.g., C. Llana and G. Wisneskey *Handbook of the Nautical Rules of the Road,* 3rd online edition, 2006 (updated in 2011), available at navruleshandbook.com/Rule5.html.
41. See SOLAS Reg. I/5 but also SOLAS Reg. I/4(b) and Art. 8 of the 1966 International Convention on Loadlines, 640 *U.N.T.S.* 133, as amended. The equivalence principle in

STCW Article IX only applies to educational and training arrangements. A limited exception exists in SOLAS Reg. V/3 that allows national exemptions and equivalence solutions in the field of safety of navigation when the absence of general navigational hazards and other conditions affecting safety 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.

42. Examples include the identification of the master on an autonomous ship and the scope of his or 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 Autonomous Ships," *NUS Centre for Maritime Law Working Paper 17/06* NUS Law Working Paper 2017/011, available at https://law.nus.edu.sg/cml/pdfs/wps/CML-WPS-1706.pdf; and R. Veal and M. Tsimplis, "The Integration of Unmanned Ships into the *Lex Maritima*," *Lloyd's Maritime and Commercial Law Quarterly*, 2017, Issue 2, p. 303.
43. See, e.g., H. Ringbom, F. Collin, and 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, available at 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* 2017, Issue 2, pp. 100–118; and the Comité Maritime International (CMI) study in IMO Doc. MSC 99/INF.8.
44. See supra note 41.
45. See further discussion in section 'Relocating Operations' below.
46. 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 Rule 2 precluding the human judgment from being provided remotely.
47. 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 avoid 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 in the text.
48. It should also be noted that the most rational decision in a given situation does not necessarily always constitute good seamanship. Unannounced maneuvers that are not commonly practiced by bridge crews, such as moving the throttle into reverse mode to avoid close contact, may be considered exceptional by fellow navigators and hence may fall foul of the standards of the ordinary practice of seamen.
49. The term "close-quarters situation" features in Rule 8 and Rule 19 of the COLREGs, but is not defined. For an attempt at defining the concept, see Helmut Hilgert, "Defining the Close-Quarters Situation at Sea," 36 *The Journal of Navigation*, 1983, Issue 3, pp. 454–461.
50. For an example of such parameters, very cautiously set, see E. Lehtovaara and K. Tervo, "B0—A Conditionally and Periodically Unmanned Bridge," 2018, available at new.abb.com/marine/articles-and-highlights/b0-a-conditionally-and-periodically-unmanned-bridge.
51. See, e.g., the conditions for operating sole lookout in daylight in STCW Section A-VIII/2, Part 3-1, para. 16, which includes factors such as traffic density, the proximity of dangers to navigation, and the availability of immediate assistance by other crew members.
52. 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*).
53. Guidelines, Annex 2, paras. 1.1.3 and 1.1.4.

54. Emphasis added. A similar requirement for the physical presence of 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."
55. STCW Code Part A, Part 4, para. 23(2).
56. STCW Code, para. A VIII/2, paras 86–89.
57. These terms are not defined in the STCW or SOLAS. Note also the tight conditions for leaving the chart room set out in para. 32.
58. IMO Resolution A.1047(27), para. 3.1.1. See also para. 1.2 of the guidelines associated to the resolution for determination of minimum safe manning.
59. STCW Code, Section A VIII/2, Part 3-1 (paras. 12–51).
60. See supra note 41.
61. 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.
62. See R. Veal and M. Tsimplis, supra note 42, at pp. 322, 328.
63. 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."
64. 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.
65. Cf. the discussions on maritime cybersecurity, which have resulted in two IMO publications in 2017: Guidelines on Maritime Cyber Risk Management (IMO Doc. MSC-FAL.1/Circ.3) and Maritime Cyber Risk Management in Safety Management Systems (IMO Resolution MSC.428(98)). Another example is the regulation of port security in the 2002 International Ship and Port Facility Security (ISPS) Code referred to in SOLAS Chapter XI-2.
66. For a summary, see e.g. IMO Doc. MSC 100/INF.3.
67. Under Art. 31(1) of the Vienna Convention on the Law of Treaties, 1760 *U.N.T.S.* 331, 1980 *U.K.T.S.* 58, as amended, 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."
68. See Carey and Veal and Tsimplis, supra note 42.
69. It is not legally problematic to grant explicit priority to subsequent and more specialized rules for partly autonomous ships in a new instrument or chapter to an existing one, provided that the parties to the instruments in question 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.M. Banaszewska, "Lex specialis," in *Max Planck Encyclopedia of Public International Law* [MPEPIL], opil.ouplaw.com/home/EPIL, last updated November 2015.
70. 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." In other words, a general provision in, for example, the STCW Convention, to the effect that its provisions shall not affect the operation of autonomous ships as defined in the new rules, would remove any incompatibility between the two instruments from a treaty law standpoint.

71. 1833 *U.N.T.S.* 33. See, e.g., IMO Doc. MSC.99/5/1 submitted by the International Federation of Ship Masters' Associations and the International Transport Federation.
72. These terms are not defined in UNCLOS, but it follows from the nature of the activities carried out by the ships here under consideration that they would most likely 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 and Ringbom, supra note 43, p. 102, who argue 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."
73. UNCLOS Art. 94(4)(b). The Danish study referred to in supra note 12, at p. 23, has highlighted this in relation to fully autonomous operations and has argued that an amendment to UNCLOS would be necessary before the IMO could proceed with regulating the matter. If this is the case, then the necessary regulatory reform would in reality have very little chance of succeeding. While UNCLOS does include some provisions on its amendment (Arts. 312, 313), they are excessively demanding and unlikely to be of use in practice. Their doubtful use seems confirmed by the fact that they have never been used, while in marked contrast, the option of negotiating an "implementing agreement" to UNCLOS has already been relied upon three times. The latter option, however, is unlikely to be suitable for present purposes, as navigational rights feature in a very large 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.
74. UNCLOS Article 94(5).
75. See CMI questionnaire of 2017 summarized in IMO Doc. MSC.99/INF.8 referred to in supra note 43, wherein 10 out of 12 responding states' maritime law associations took a similar view of UNCLOS and considered that the IMO has the formal competence to regulate unmanned ships.
76. But note the fairly broad terms of reference of the IMO working group quoted at supra note 3.
77. See www.imo.org/en/OurWork/Safety/SafetyTopics/Pages/Goal-BasedStandards.aspx.
78. 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.
79. *Ibid*. See also IMO Circular MSC.1/Circ. 1394 (Generic Guidelines for Developing IMO Goal-Based Standards).
80. 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 toward goal-based and prescriptive standards and its holistic risk-based approach, but also as regards its form, given that the Polar Code amended several key IMO conventions. See also M. Bergström, S. Hirdaris, A. Lappalainen, O.A. Valdez Banda, P. Kujala, and O-V. Sormunen, "Towards the Unmanned Ship Code," in P. Kujala and Liangliang Lu (eds.), *Marine Design XIII, Volume 2: Proceedings of the 13th International Marine Design Conference (IMDC 2018), June 10–14, 2018*, Helsinki, Finland, CRC Press, 2018, www.crcpress.com/Marine-Design-XIII-Volume-2-Proceedings-of-the-13th-International-Marine/Kujala-Lu/p/book/9781138340763.