Development of International Regulations for Autonomous Ships

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Abstract:
This paper first focus on identifying international regulations that are obstacles to the development of autonomous ships. It is concluded that there are no serious obstacles to the continuous development of autonomous ships, whilst there are numerous obstacles to unmanned international shipping. It is therefore advisable to keep the two issues separate. The development of more automated navigation has been a gradual development over many years, and a large portion of the sailing ship can navigate by autopilot, following routes defined by waypoints set by the master prior to the voyage commences. Service providers also deliver weather and fuel optimized routes for the autopilot to use during navigation. Such solutions reduce fuel consumption and emissions to air. For military use, there are also unmanned smaller crafts e.g. used for surveillance, as well as larger unmanned minesweepers.
The paper argues for an alternative regulatory system for autonomous ships, which builds on the IMO work with Goal Based Standards/Safety Level Approach. The approach is illustrated by examples of goals and functional requirements, as well as suggestions for how the details rules shall be developed and compliance verified. The proposed solution is seen as a natural progression of the IMO work on applying risk based approaches to regulatory development.

1. Introduction
The development of autonomous and unmanned ships has recently become a hot topic. Several research projects have been carried out and many research papers published. There are dedicated seminars and symposia organized, covering such topics as autonomous navigation technology, automated onboard systems, e-navigation, automation software, remote control, economic benefits, legal and regulatory implications, testing and validation.
From a regulatory point of view, it is not the autonomy, that pose a challenge. The challenge is when autonomy results in reducing manning below the lower limit in current regulations. Obviously, when this happens the regulations needs to change, or those ships are not permitted to sail in international waters. The topic of the paper is limited to ships under international regulations. The definition in SOLAS Chapter I is therefore used to limit the discussion: ships engaged on international voyages, except (i) Ships of war and troopships, (ii) Cargo ships of less than 500 gross tonnage, (iii) Ships not propelled by mechanical means, (iv) Wooden ships of primitive build, (v) Pleasure yachts not engaged in trade; and (vi) Fishing vessels.

2. The current IMO work
Autonomous ships were put on the agenda of MSC at MSC98 (June 2017), based on an initiative by Denmark et al. [1]. The proposed task for IMO was to carry out a regulatory scoping exercise with the aim of identifying:
1. IMO regulations which, as currently drafted, preclude unmanned operations;
2. IMO regulations that would have no application to unmanned operations (as they relate purely to a human presence on board); and
3. IMO regulations which do not preclude unmanned operations but may need to be amended in order to ensure that the construction and operation of MASS are carried out safely, securely, and in an environmentally sound manner.

Four sessions of MSC was proposed to be used for this, implying that the study will be finalized in May/June 2020. No work on amending any regulations is currently planned.

ITF submitted a commenting paper. Amongst other proposed actions, ITF proposed to consider implications of IMO treaty regimes and UNCLOS for unmanned ships.

There was general support for both proposals. If the scoping exercise concludes that UNCLOS needs to be amended, this is outside IMO jurisdiction and will delay the process. MSC99 (May 2018) decided to limit the scoping to instruments under its purview.

The IMO Legal Committee (LEG 105, April 2018) also agreed to carry out a scoping study of instruments under its purview based on a submission by Canada et al. [2]. The scoping should
1. identify provisions of those conventions that preclude unmanned operations;
2. identify provisions of those conventions that do not apply to unmanned operations;
3. identify provisions of those conventions that do not preclude unmanned operations but that would need to be amended to acknowledge differences in the operation of unmanned operations; and
4. identify other gaps in the existing regulatory framework that would need to

The scoping is expected to be completed in 2020-2021 biennium.

The Head of the IMO Legal Department participates in UNCLOS regular meetings. The question relating to UNCLOS amendments will initially be handled by her. In any case the interpretation of such provisions is the prerogative of the Parties to UNCLOS.

It is clear from scoping studies already published that both the Maritime Environmental Protection Committee (MEPC) and the Facilitation Committee (FAL) need to carry out similar scoping studies. This has not yet been proposed.

The IMO secretariat seem to have a different view and proposed that MSC99 first agreed on the approach. In [4] it was proposed agree on the choice of instrument, with 4 alternatives:

1. amending existing instruments, taking into account the different amendment procedures for specific instruments or regulations and the time and means required to bring the necessary amendments into force; or
2. developing a new separate instrument addressing MASS; or
3. a combination of options 1 and 2 above; or
4. the development of interim guidelines to gain experience before commencing work on mandatory requirements.

This proposal was not discussed at MSC99, but will hopefully be discussed later.

3. An alternative approach

In IMO Conventions and Classification rules the use of the term ‘alarm’ is an indication of a need for a revision in the case of un-manned ships, since in most of these cases the assumption is a human intervention onboard. A search in IMO-Vega for ‘alarm’ produces 889 documents, some of which contain the term many times. Similarly, a search for ‘alarm’ in IACS UR M (Machinery) show that the term is used about 180 times. Other URs and individual Class Rules will indicate further challenges and needs for alternative rules and regulations for autonomous and un-manned ships. Similarly, a search for ‘manual operation’ identifies 84 documents in IMO-Vega. It therefore takes only seconds to conclude that the approach by the IMO Scoping Study, which seems to correspond to alternative 1 in [4] is impractical. It would take ‘forever’ to amend all provisions in all conventions from the current version into two different new versions, one for remotely controlled ships and one for autonomous ships.

The focus should rather be on option 2 in [4]. However, some explicit showstoppers in some of the important regulatory instruments must be removed. In this sense option 3 should be supported. However, an independent instrument should be developed first, followed by consequential amendments to other conventions. Option 4 could also be an interim solution. This may be linked to STCW/I/13 where there is already a reference to a non-existent guideline for trials in international waters. Paragraph 3 of STCW/I/13 reads “The Administration authorizing ships to participate in trials shall be satisfied that such trials are conducted in a manner that provides at least the same degree of safety, security and pollution prevention as provided by these regulations. Such trials shall be conducted in accordance with guidelines adopted by the Organization.” Since such Guidelines does not exist, the first task could be to develop such guidelines. There would not be any need for amending any convention.

The scope of work should also be reduced. It is not very likely that there is a need for unmanned Nuclear Fuelled ships, Passengers Ships, High Speed Crafts, Wing in Ground Crafts etc. The chances of progress would be better if the scope was limited. For example, in [5] it is proposed to focus on “unmanned cargo carriers”. The term “cargo carrier” would then have to be defined. Currently this is not a defined ship type in IMO instruments.

There are essentially three different ways to develop IMO regulations for Autonomous Ships:

1. The current conventions, codes and other instruments are amended to permit autonomous operations (This seems to be the proposal in the scoping study).
2. A new convention is developed that applies only to autonomous ships.
3. A new Code is developed, and made mandatory for autonomous ships by anchoring the Code in a new Chapter in SOLAS, followed by a process of consequential amendments of other conventions.

To amend all conventions is going to be an extremely time consuming task. It is not believed that this approach would be practical. It will be involving all IMO committees and Subcommittees and most conventions and codes.

A new convention would be simpler to develop, as it would only apply to autonomous ship. However, no ship would be only autonomous, it would be a ship type, with a specific cargo and...
be autonomous. Multiple conventions and/or codes would apply to an autonomous ship. The requirements would also in this case need to be formulated in at least two versions: Fully autonomous and remotely controlled, and in various combinations of autonomous and remote control. This could only be avoided, if the new convention was goal based, and the functional requirements formulated sufficiently generic to be applicable for both cases (and any cases in between). The challenge of ratification would remain. It would take time, and it would be very uncertain how long it would take until a new convention was ratified, if ever.

A new code would be a simpler and more practical case. Many of the same challenges as for a new convention would be relevant for a new Code. However, if the code was made mandatory under SOLAS (A new SOLAS Chapter as anchoring point), the use of the code would have the same application as a convention. If mandated by 2/3 majority, this avoids the ratification challenges.

The recommendation is therefore: A new Code “Autonomous Ship Code (ASC)”, anchored and mandated in SOLAS. This needs to be followed by consequential amendment of other conventions. However, when an ASC Code is adopted consequential amendments can be done mainly by referring to the code.

It is expected that the enabling technology applicable to autonomous ships are developing fast. New and better technology will enter the market frequently. It is therefore not practical to formulate detailed technical requirements (for algorithms, sensors, data-fusion etc.) at the IMO level. The new Code should therefore be Goal Based. The goal of the Goal Based Code should be ‘Autonomous ships shall be as safe as conventional ships of the same type’ (or some similar formulation). This would be a standard formulation, used in many IMO instruments, including the STCW/I/13 procedure mentioned above.

It should be left to the class societies to develop the detailed rules that comply with the ASC.
Class societies would then have to document that the Rules result in equivalent safety. This is nothing new to class societies involved in Alternative design, which is extensively used in particular for cruise ships.

4. **The main showstoppers for un-manned ships.**

It may be understood from [3] that there is a virtually endless list of amendments required in the IMO instruments to allow for MASS if alternative 1 in [4] is the preferred approach. However, the showstoppers do not relate to autonomy, but manning. There are few, if any, showstoppers for introducing more autonomy on ships as long as the ship is manned. The most explicit showstoppers for manning is in STCW, Watchkeeping, Regulation VIII/2. The challenge is to use the term “physically present” on-board. Regulation VIII/2:

> “2 Administrations shall require the master of every ship to ensure that watchkeeping arrangements are adequate for maintaining a safe watch or watches, taking into account the prevailing circumstances and conditions and that, under the master’s general direction:
> 1 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;
> 3 officers in charge of an engineering watch, as defined in the STCW Code, under the direction of the chief engineer officer, shall be immediately available and on call to attend the machinery spaces and, when required, shall be physically present in the machinery space during their periods of responsibility;”

Paragraph 2.1 needs to be amended to reduce the manning below current minimum levels, whilst paragraph 2.3 allow the reduction to one chief engineer, in case there are sufficient automation and support from a remote control centre. This is four crew.

There are already resolutions available at IMO that demonstrate that there are options for reducing manning under certain conditions. Assembly resolution A.1047(27) [6] on Safe Manning demonstrates that IMO Assembly has thought of the effect of much automation and support from on-shore in deciding on safe-manning, although the purpose was not to prepare for un-manned ships.

“The minimum safe manning of a ship should be established taking into account all relevant factors, including the following:

3 level of ship automation;
10 degree of shoreside support provided to the ship by the company;

The Administration may require the company responsible for the operation of the ship to prepare and submit its proposal for the minimum safe manning of a ship in accordance with a form specified by the Administration. It is worth noting that on this subject, the flag state may expect to be audited per the IMO Instruments Implementation Code [7] “A flag State should ensure that ships entitled to fly its flag are sufficiently and efficiently manned, taking into account relevant and existing measures such as the Principles of Safe Manning adopted by the Organization.”

In addition to the four crew barrier in STCW, the other barrier is when the master is no longer on-board. Over the years there is a long list of duties assigned to the master in various instruments. For example, in SOLAS II-1, regulation 5, paragraph 4 “Where any alterations are made to a ship so as to materially affect the stability information supplied to the master, amended stability information shall be provided”, in SOLAS III, Section II, Regulation 27 “Details of persons who have declared a need for special care or assistance in emergency situations shall be recorded and communicated to the master prior to departure”. In the ISPS code there is a defined position as ship security officer, but this can be the master. Still 5.4 “The Declaration of Security shall be completed by: 1 the master or the ship security officer on
behalf of the ship(s)” will be problematic if the ship is un-manned. These are just some examples, that demonstrates that there will be a lot of requirements assigned to a person that will not exist on an un-manned ship. For the conventions on liability and compensation under the purview of the IMO Legal Committee, this will also be a challenge. Furthermore, Coast Guards, Search and Rescue Services, Vessel Traffic Centers, Pilots and Ports may be in a need to be able to communicate to a person responsible for the ship. It is therefore believed that for the ultimate level of autonomy there will still need to be an identifiable person responsible for the ship that can be contacted. This will, for an un-manned ship, be a person in the control centre. It is believed that this person may replace the role of the master in many regulatory instruments, and that totally autonomous ships without a remote-control centre is not realistic in the foreseeable future.

5. Regulatory system for autonomous ships

Interim Guidelines
It is expected that there should be trials of autonomous ships in international waters to gain experience prior to adopting mandatory instruments (alternative 4 in [4]). The debate at MSC99 indicated that many would like to see objective reporting of experience from operation of autonomous or remotely controlled ship to IMO as early as possible. Interestingly this procedure already exists. This is STCW I/13, which allows Administration authorizing ships entitled to fly its flag to participate in trials. Trial means an experiment or series of experiments, conducted over a limited period, which may involve the use of “automated or integrated systems in order to evaluate alternative methods of performing specific duties or satisfying particular arrangements prescribed by the Convention, which would provide at least the same degree of safety, security and pollution prevention”. It is noted, that also in this procedure, the principle is equivalence, as suggested for the ASC.

STCW/1/13 contains requirements to reporting to IMO six months prior to commencing trials and to reporting results of the trials. This information shall be circulated to all parties. Any Party having any objection to trials authorized should communicate such objection to IMO as early as practicable. IMO shall circulate details of the objection to all Parties. An Administration which has authorized a trial shall respect objections received from other Parties relating to such trial by directing ships entitled to fly its flag not to engage in a trial while navigating in the waters of a coastal State which has communicated its objection to IMO.

An Administration which concludes, based on a trial, that a system will provide at least the same degree of safety, security and pollution prevention may authorize ships entitled to fly its flag to continue to operate with such a system indefinitely, under specified conditions. At the request of any Party, the Maritime Safety Committee shall establish a date for the consideration of the trial results and for the appropriate determinations.

STCW/I/13 §3 and §8.2 refers to guidelines adopted/developed by IMO. These are Guidelines that do not exist, and may be developed for each type of trials. It is therefore possible to develop the interim guidelines (4 in [4]) that allow trial with autonomous ships without amending any convention or code.

The ASC Code
Any autonomous or remotely controlled ship will also belong to one of the ship types in the conventions and carrying specific cargos. The ASC code will therefore have to state which chapters in SOLAS and other instruments that applies unchanged. For example, all requirements to structural strength should also apply to autonomous or remotely controlled ships. Some argue that if there is no people on-board the requirement to fire protection could
be relaxed, due to the reduced consequence. Whilst such arguments may be rational, it is not likely to be wise to start the development of regulations of autonomous ships by reducing safety. If a ship is un-manned always, there is no need for accommodation, lifesaving appliances and several support functions. However, this is a big step. It may be difficult to guarantee that a ship will never be in need for a maintenance crew on-board.

**Remote Control Centre**

The remote-control centre and the communication requirements between the ship and control centre will require new regulations. Currently many of the large ship equipment manufacturers run support and monitoring centres. These centres aid and guide, but provide no active command and control. The setup is similar. Three centres are set up in three different time zones, 8 hours apart, and responsibility is transferred every 8 hours. The personnel in the centres therefore have normal 8AM-4PM working hours. For the control centres this setup might cause challenges for the conventions on liability and compensation under the purview of IMO LEG. It may be assumed that a company running such centres will remotely control ships from different flags, different owners and be located in three different countries, none of which is the country of the flag state. The centres should probably be regulated under maritime law for its essential functions. In any case, the legal issues seem not to be trivial to resolve and should be a key topic for the work of IMO LEG.

The safety issues need to be dealt with in IMO MSC and subcommittees. The centres themselves need to have strict requirements to both cyber and physical security. There need to be requirements to bandwidth and latency, and there need to be two independent communication links between the ship and the control centre. No common cause failure should be able to shut down both links.

Since a control centre will most likely control a number of ships, the presentation of information from each ship and the control functions to be carried out from the control centres need to be standardized, if not the likelihood of human error will most likely be unacceptable high.

**Navigation Algorithms.**

The current navigators are trained and certified per STCW. In addition, many owners invest in extra regular simulator training. Equivalently, the navigation algorithms will need to be certified after thorough testing. Current ships sail on average more than 100 years between collisions. Groundings are more frequent. Currently, there are no testing procedures available for navigation algorithms. It is still in the research domain how the testing should be carried out. The most obvious solution would probably be to use navigation algorithms on manned ships, with detailed recording of their performance. At some point, sufficient confidence in the algorithms could be established. The alternative is that the algorithms are tested in some sort of simulated environment. It is not obvious how this could be done, but there are various proposals in the research domain.

The situation awareness need to be established by sensors, sensor data analysis and data fusion. For grounding, there is no need for new sensors for ships with ECDIS. The ship already has all information needed, and many ships already have grounding avoidance systems. In such systems, there is a check that the ship will not ground for a predefined track defined by set waypoints. The missing part is an algorithm that propose tracks and chose one that does not result in grounding.

For collision avoidance, there is no agreed set of sensors that will provide the situation awareness. This is expected to be based on different types of radars, AIS, cameras (visual & infrared), LIDARs and sound processing (equivalent to sight and hearing in SOLAS). The possible assurance frameworks for autonomous navigation systems with emphasis on testing and verification of the systems perception performance and capacities is discussed in [8].
Research has revealed challenges related to artificial situation awareness and machine perception specific to the marine environment. The lack of a clear and transparent framework and methodologies to assure the safety associated with the usage of such solutions, has been identified as key barriers for the implementation of autonomous navigation. Because the machine perception and situational awareness algorithms are expected to be partly or fully based on machine learning algorithms, including deep learning, whose functional reasoning is challenging or even impossible to understand and predict, the verification of such systems is fundamentally different from a traditional verification process based on physical understanding and theory.

For both collision and grounding algorithms the challenge is that the algorithms will be ship specific, because e.g. hydrodynamic properties, manoeuvrability, ship stopping distance and turning radius differs.

**Voyage Data Recorder**

An autonomous function can acquire information, analyse it, plan needed changes of control parameters and effectuate changes. A ship is autonomous if all its functions are autonomous (=self-governing). A function can be manually controlled, remotely controlled or autonomous. On a ship, some functions may be manually controlled, some remotely controlled and some autonomous. Switching between these modes may happen as function of time, operations, events etc. An autonomous ship or a remotely controlled ship may be manned or unmanned. A remotely controlled ship may need much autonomy to avoid too high demand for bandwidth. Because of such complexities, and switching between responsibilities there will be a need for a completely new specification for the voyage data recorder, which also needs to keep track of responsibilities for each function at any point in time. The VDR should also be moved from the ship to the remote-control centre or some cloud-storage.

**6. Conclusions**

The current IMO work is based on an understanding of the scoping study that result in a detailed review of all IMO instruments, paragraph by paragraph and identify necessary amendments. This is typical bottom-up process. This work is not very productive, as following this approach will result in an almost endless need for changes. The solution is to develop a separate code, and mandate the code by anchoring this code in SOLAS. This will need to be followed up by consequential amendments of other conventions. However, since there is an agreement on the most important safety issues in the ASC when anchored in SOLAS and mandatory, most of the consequential amendments will not be very difficult.

The exception is the convention on Liability and Compensation under the purview of the IMO Legal Committee. To deal with the challenge it is necessary to agree that there will always be a person responsible for the ship in the remote-control centre. It will need to be agreed that this person can replace the master in these conventions, and in many codes where the master has been assigned a duty. If this is not accepted, there will most likely not be un-manned ships in international trade.

There is also a lot of other standards that needs to be developed. The most demanding is the standard for the remote-control centres, standards for verification and certification of navigation algorithms and a new standard for the voyage data recorder.
References:

[1] Denmark, Estonia, Finland, Japan, the Netherlands, Norway, the Republic of Korea, the United Kingdom and the United States (2017) 'Maritime Autonomous Surface Ships, Proposal for a regulatory scoping exercise', MSC 98/20/2

[2] Canada, Finland, Georgia, the Marshall Islands, Norway, the Republic of Korea, Turkey, CMI, ICS and P&I Clubs (2018) ‘Proposal for a regulatory scoping exercise and gap analysis with respect to Maritime Autonomous Surface Ships (MASS), LEG105/11/1


