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ANY OTHER BUSINESS

Future-proofing the maritime safety regime

Submitted by ICS, IUMI, IACS, P&I Clubs and CIMAC

SUMMARY

Executive summary:	This document informs the Committee of the work in the Joint Industry Working Group (JIWG), which was established between IACS and other maritime industry organizations to consider the impact of digitalization and increasingly complex systems on ships, and the introduction of advanced survey techniques. To help define the extent of potential risks associated with complex systems, a problem statement was developed and an industry survey was conducted to validate it. Examples of relevant incidents were then collated and reviewed. The group concluded that the trend of integrating more advanced technology on ships is leading to increased safety risks and that the adoption of systems engineering techniques, robust interface management and better clarity regarding stakeholder responsibilities would help the maritime industry to address those risks. As data analysis capabilities grow, advanced survey techniques are becoming an option in combination with traditional survey. The JIWG considered that further work on this topic is necessary.
Strategic direction, if applicable:	2, 3 and 6
Output:	Not applicable
Action to be taken:	Paragraph 73
Related documents:	None

Background

1 In 2019, the cruise ship **Viking Sky** experienced a blackout which, due to system and environmental interactions, lasted 39 minutes before propulsion was recovered. The ship is estimated to have come within a ship's length of running aground with over a thousand people on board. The conclusions of the NSIA report[1] identify contributing factors, specifying that "The situation was stressful, the control system was complex, and a specific sequence of actions was needed." Actions were recommended on regulation, design, assurance and procedural controls.

2 There is a common understanding that the current regulatory processes are adequate for risk mitigation; however, this assumption warrants re-examination considering the rapid transformation of maritime technology to support decarbonization[2] and increasingly automated and autonomous operation.

3 In the worst cases, scenarios which were not anticipated under traditional risk assessments could lead to loss of life or to the release of a toxic fuel near a populated area, with catastrophic consequences.

4 Unexpected and undesirable incidents may occur as consequences of adopting novel designs or concepts. Therefore, it would be preferable to adopt a proactive approach to avoid potential threats to lives and livelihoods rather than to wait and learn from incidents.

5 At the same time, with the move towards decarbonization, the anticipated benefits of digitalization[3] are driving the adoption of increasingly interconnected computer-based systems, either within a single ship, a network of multiple ships or between ships and shore. Industry stakeholders have indicated that future ship data architectures may evolve into onboard data centres[4], enabling the use of common information by software applications both on board and ashore. While widespread data sharing can introduce cyber vulnerabilities, it enables new insights, such as the application of computer-aided route planning to help address the challenges of safe decarbonization. Crucially, the access to shared data and its effective analysis can help bridge the knowledge gap between regulators and industry developers, supporting more informed and adaptive regulatory oversight in the face of rapid technological change.

6 With an increase in digitalization and integration, systems on ships interact with each other in complicated ways which were not previously considered. The ship itself may be a complicated integrated system which can still be modelled and predicted. However, if one then implements the system to interact with the changing environment and with other data traffic, it would no longer be possible to fully predict the system's behaviour. Complex systems are characterized by system behaviour which is intrinsically difficult to model or predict because of the many mutually interacting and integrated design elements which influence the emergence of its final behaviour (see annex 1 for more detailed discussion on the definition of "complex systems"). There are imminent concerns associated with aspects such as responsibilities imposed by complex systems in cases of incidents. There is the necessity for sufficient understanding by crews and operators of such complex systems to avoid risks occurring from improper operations or troubleshooting.

7 Increasing system complexity raises the risk of incorrect interfacing of sub-systems, not only digitally but also in terms of hydraulic, pneumatic, electrical and structural connections. The root cause of such issues could be contractual, i.e. where the responsibility for providing a correctly configured interface may be omitted from a sub-contract or incorrectly specified. It could also be due to poor workmanship or failure to correctly transfer the specified interface requirements to the detailed construction documentation.

8 Another emerging concern is the method for conducting surveys of both conventional and increasingly complex systems. For components of a traditional ship's system, which are independent and self-contained, the time-based survey scheme (periodical surveys) is considered sufficient to assess the condition, confirm that the system remains compliant with regulatory requirements and continues to be operational. On the other hand, taking into account that ships' systems are increasingly becoming able to self-monitor their own state and alert the crews/owners in cases of the need for interventions, it is questionable whether the time-based survey method would be the most effective and efficient method, especially when the system would only need to be attended at certain times or when it is in degraded condition.

9 The increasing complexity of maritime systems and operations has made the outcomes of applying existing safety regulations less predictable. To collaborate on this challenge, a diverse group of interested industry stakeholders came together as a Joint Industry Working Group (JIWG) to explore how the maritime regulations could be made to remain effective, relevant and achieve the goals of safe and environmentally friendly operation of ships at a pace matching that of industrial innovation.

Terms of Reference

10 The Terms of Reference of this JIWG aim to identify risks associated with the deployment of complex novel technology on board ships in the context of the existing SOLAS survey and certification regime, the need to address those risks and identify opportunities - the challenges and potential solutions, as seen by the various stakeholders.

11 Two connected, but separate, issues were covered:

.1 the implementation of advanced and increasingly complex, often digital, technologies which support the operation of ships' systems and fall outside the normal requirements prescribed by SOLAS; and

.2 the application of advanced, often digital, technologies providing insight into actual and predicted condition of a ship and its systems, which may offer an alternative to traditional time-based survey regimes required by statutory regulations.

Discussion

12 The JIWG meetings were held between June 2022 and January 2026 with intersessional discussions conducted through correspondence. Areas discussed included:

.1 Statutory regulations lag technology development. Where assessment is based upon equivalence, the current required level of safety is not clearly defined for the purpose.

.2 As complexity increases, National Authorities and classification societies may not maintain technical competence across the entire range of technologies and systems. As a result, there may be insufficient regulatory oversight and analysis of the compelling body of evidence to demonstrate that the system (system-of-systems) is safe to operate in a defined context of use unless a wider group of relevant stakeholders is involved.

.3 Putting focus on system integration to address complexity challenges requires clearly defined responsibilities for the wider group of stakeholders, to ensure the competence and coverage which is necessary to conduct effective assurance.

.4 Ship data quality is important for the correct and safe function of complex computer-based systems and for the digitalization of survey activities. IACS and industry bodies, such as CIMAC, are working to provide guidance on aspects of data quality and data management.

.5 Where humans remain a part of the decision-making process, human-centred design must be considered to ensure that the human element is properly addressed.

.6 To account for uncertainty, there is merit in adopting inherently safe design principles, using industry's best practices rather than relying on minimum standards.

13 To assist with the JIWG's understanding of the issues faced by the maritime industry, the group developed and circulated a questionnaire which included a draft problem statement.

Questionnaire results

14 Responses to the questionnaire (annex 2 and located on the IMODOCS Virtual Portal of MSC 112) supported issues identified in the problem statement. There was less certainty in the answer regarding the level of understanding of design principles; therefore, the problem statement was updated to reflect that understanding.

Problem statement

15 Considering the questionnaire results, the JIWG agreed the below problem statement:

"The rapid adoption of new technologies to meet multiple objectives leads to complex implementation challenges in a traditional maritime industry. This may result in an unsafe state on board ships as they operate. Considerations of safety, business performance, operations and environmental performance are further complicated by the transfer of crew functions to technical systems on and off the ship.

A lack of understanding of the ship as a system, the changing role of the human operator, and the multiplicity of approaches create integration and assurance challenges. These challenges are not obviously addressed by existing rules and regulations.

While SOLAS offers generic alternative routes to qualify novel technologies, the objective baseline to be achieved and the means of consistently demonstrating compliance may not be either clear or practically applicable. Regulations do not consider alternatives to time-based survey regimes.

Consequently, the anticipated benefits of technical advancement cannot be fully realized until the associated risks are systematically identified, understood and managed throughout the entire system lifecycle. Without future proofing the regulatory response and in the absence of regulations that account for evolving system complexity, there is a growing concern that maritime safety could be compromised."

Alternative to traditional time-based survey mechanisms

16 Present-day surveys are carried out under the time-based survey scheme in which a surveyor visits the subject ship to examine the condition of the ship and its systems using traditional survey techniques and technologies.

17 Survey techniques can be separated into those considered to be "traditional" and those which are "advanced", with the following examples:

.1 examples of traditional survey techniques and technologies:

.1 surveys carried out in person and witnessed by a surveyor who may bring supporting items (e.g., the sketch or drawing, flashlight, hammer, measuring devices and imaging equipment such as cameras/binoculars/borescopes etc.);

.2 visual examinations and review of data, reports, videos, photos, etc.; supported by remote surveys with the support of information and communication technologies (such as live streaming of audio, video and data);

.3 non-destructive tests (NDT), pressure tests, leak tests; and

.4 close-up examination of areas hard to reach by using permanent means of access (PMA), cherry pickers, ladders, staging or man lifts; supported by rope access (by technicians), and by Remote Inspection Techniques (RIT) such as remotely operated vehicles, climbers, crawlers, elevating platforms, drones; and

.2 examples of survey techniques and technologies which may be considered as advanced:

.1 data-driven verification;

.2 reliability verification;

.3 Condition Based Maintenance (CBM) using monitoring device/equipment;

.4 risk-based inspection;

.5 strain gauge for stress recording and analysis;

.6 self-checking functionality;

.7 advanced non-destructive examinations (NDE) such as UT phased array or eddy current thickness measurement; and

.8 laser scanning.

18 The current regulatory regime allows for the use of "traditional" survey techniques under the HSSC (Harmonized System of Survey Certification), involving periodical surveys. While individual National Authorities and classification societies, in cooperation with manufacturers, have been making efforts to conduct surveys using some "advanced" survey techniques and technologies, such as remote surveys, the regulatory regime may need to adapt to enable the regular use of the "advanced" survey techniques and technologies. This would promote future developments and the use of even more advanced concepts, as they become available.

19 Data analysis which tends to focus on known problem areas can complement traditional ship surveys which are better at identifying and picking up new problems; however, it is unlikely to replace them entirely. As both data analysis and traditional surveys have their strengths and limitations, a combination of both approaches may provide the most comprehensive assessment of a ship's condition. CIMAC is working on projects with several classification societies to develop the concept of "machine-based surveys"[5].

20 Smart software incorporating new levels of self-checking functionality provides an additional source of information related to the condition of the system.

21 All these technologies (on board and ashore) offer alternatives to time-based survey regimes. Presently, regulations do not provide for condition-based surveys whereby the performance and/or the condition of a component is used to determine the schedule and scope of examination or disassembly. The amendments to the 2011 ESP Code, which were adopted by MSC 111, will enter into force on 1 January 2028; they will allow the use of RIT in the surveys addressed by the ESP Code.

Example incidents

22 While it is not possible to find evidence of failures in future designs, examples of incidents on current designs were discussed to identify any relevant learning, as summarized below.

23 Example 1:

.1 The chemical tanker **Northsea Rational**, after departing Hamburg on 25 November 2020 and en route to the North Sea, collided with the quay wall resulting in significant damage to its forecastle and the quay itself. During the switching operation (from manual to auto-pilot), the rudder suddenly moved to starboard quickly and unintentionally (reaching a rudder angle of 26.7°) and then it returned to midships position. At 10 knots speed, this rudder deflection caused the ship to turn starboard; in spite of the bridge team's efforts to go full astern and attempting to let go the port anchor to reduce the speed of the allision with the quay wall on the northern side of the Elbe River.

.2 Although there was damage to assets, there were no injuries or environmental harm from this accident; the investigation report[6] identified a number of aspects and addressed several issues. During the ship construction phase, data transmission from the autopilot to steering gear control was not configured according to design requirements. Relays which were originally not envisaged in the circuit diagram had been installed in the steering gear control panel. This caused the steering gear to work at full power with every steering command, resulting in continuous overshooting and counter steering (paddling). On the one hand, this led to a heavy load on the components of the steering gear; on the other hand, this resulted in extremely high switching frequency within the electrical components. As a result, the relays were particularly affected by this, leading to premature wear and finally short-term failure of one of these relays, which was the direct cause of the accident.

.3 Analysis: even in this relatively simple example there are issues with system integration, responsibilities of involved stakeholders and system understanding during design, design verification and operation. This is in spite of the fact that the ship was compliant with SOLAS regulation II-1/29 (steering gear). Interconnections resulted in unintentional behaviour caused by interactions between systems.

24 Example 2:

.1 During commissioning trials of alternators on a new build ship, a critical System of Systems (SoS) failure occurred due to the bypassing of the dedicated UPS which powered the safety system of the prime mover. The trials were conducted using shore power; when this single power source failed, both the control and protection systems for the prime mover were lost. This led to an uncontrolled engine overspeed event which caused catastrophic mechanical damage: the alternator rotor was destroyed, jammed against the stator, and the entire alternator was ripped from its bed plate. Although no injuries occurred, the financial consequences were significant.

.2 The incident highlights a failure to evaluate the risks associated with using a single source of electrical power during commissioning. Under normal conditions, two independent power sources would have protected the system; one for control and one for safety. However, the lack of redundancy during this specific use case exposed a single point of failure which proved intolerable. This event underscores the importance of considering all operational scenarios, including commissioning and dry dock periods, when designing and validating integrated systems.

.3 Analysis: the risks associated with the use of a single source of electrical power for the trials were not evaluated, resulting in an intolerable risk. There was no loss of human life. At the same time, significant financial implications occurred. This can be associated with a SoS failure to consider all use cases – commissioning, dry dock periods.

25 Example 3:

.1 The drill ship **Norbe VIII** operating off the coast of Brazil at the Marlim Oil Field suffered a catastrophic boiler failure during routine maintenance of its auxiliary boilers. The incident occurred when two service technicians and a second engineer were working in the boiler room, attempting to restart the boilers after repeated shutdowns caused by abnormal pressure safety valve behaviour. The investigation[7] revealed that the flame scanner sensor and pressure safety systems were not functioning correctly, leading to repeated boiler restarts under hazardous conditions.

.2 Similar incidents have been reported leading to main oil-fired boiler events, where the main oil-fired boiler suffered a "pressure pulse" which destroyed the furnace, ruptured the boiler tubes and required extensive repairs to return the boiler to operational status.

.3 Condition: the boiler was being fired and on test – the software-based flame scanner failed to detect a "flame out", so the fuel was being pumped into the furnace. The operator restarted the boiler; however, the purge cycle failed to remove all the fuel and upon ignition the resulting "pressure pulse" damaged the boiler.

.4 Analysis: the flame scanner is a safety device; the scanner was supplied as part of the boiler control system from the boiler manufacturer. However, the software development was outsourced; upon questioning, the software developers were unaware that the code was being used for a flame scanner, or that the scanner was used as a safety device. There were no requirements placed on the software developer to develop software in accordance with an International Standard.

.5 Timing issues were identified as the root cause of the event. No loss of human life occurred. At the same time, significant financial implications occurred. This event highlighted the controls required throughout the supply chain and consideration of the application of the software within an SoS environment.

26 Example 4:

.1 A published CHIRP report describes an incident involving an unnamed superyacht that experienced a partial loss of power during arrival into a confined harbour. The failure was traced to a remote software update on a galley refrigeration unit, initiated by the supplier without notifying the yacht, which caused an unexpected load spike.

.2 Similarly, many other over-the-air software update incidents have occurred. In one case, the engine room ventilation manufacturer had the ability to carry out over-the-air software updates; a service which is now seen from several manufacturers. The manufacturer carried out the update which required the ventilation system to re-boot. This resulted in the ventilation fans stopping, dampers closing and then restarting. Unknown to the manufacturer, the ship was at sea, with two main engines running. The loss of ventilation and closing of the dampers resulted in the air within the engine room space being consumed by the engines. The Chief Engineer was in the engine room space and managed to open a watertight door to exit the machinery space.

.3 Analysis: the manufacturer did not contact the ship's staff before carrying out the update; they sold this as a benefit for the owners. The Chief Engineer did not know that this facility existed and was shocked to discover that there were other systems on the ship with the same facility to carry out over-the-air updates. The ventilation manufacturer stated that there were no requirements within their maintenance contract to contact the ship's staff when carrying out the updates.

.4 Potential loss of life with an environmental risk; lack of trust and lack of consideration of the risks at an SoS level, representing a supply chain assurance challenge.

Lessons from other industry sectors

27 Within the offshore floating production sector, the interfaces between the complex onboard systems can include digital, electrical, hydraulic, pneumatic and flange connections. These are often situated between the process modules, but will also include connections between the shipboard systems and process modules for supply of control, monitoring, electrical and hydraulic power, cooling water etc. These connections are more numerous than would normally be seen on board a merchant ship. Noting the ever-increasing complexity of shipboard systems, an understanding of how such interfaces are managed during the design and construction of a Floating Production Unit (FPU) may be of relevance when considering options for mitigating the associated risks within merchant ships.

28 Although not a mandatory or classification requirement for FPUs, it is best practice to assign the management of interfaces to an interface manager who would normally be part of the owner's supervision team. From an early stage, that manager will work closely with the equipment and module suppliers to identify all the interfaces and to record them, either using a spreadsheet or, more commonly nowadays, with specialist software. During the development of the facility, the manager will then ensure that the necessary interface requirements are being met by the suppliers. This may be done by:

.1 specifying the interfaces within the contract documentation for each supplier;

.2 holding regular interface meetings with suppliers;

.3 verifying correct interfaces through the plan approval process;

.4 inspection of interfaces at shop tests and on board; and

.5 testing of interfaces through the commissioning process.

29 Specialist software may also be used to track the development of interfaces during design and construction phases.

30 This methodology has been found to be beneficial, both in terms of the efficient construction of facilities, and for assuring their safe operation.

31 Example 5:

.1 The Boeing 737 MAX accidents, which resulted in a total of 346 deaths, were primarily caused by failures in the interfaces between complex onboard systems, particularly the Maneuvering Characteristics Augmentation System (MCAS). MCAS was designed to automatically adjust the aircraft's pitch based on the input from a single Angle of Attack (AoA) sensor, without cross-checking data from the second sensor. The flight control system generated multiple conflicting alerts, overwhelming pilots and obscuring the root cause of the malfunction.

.2 Some of the key lessons learned, particularly in relation to system interfaces and safety engineering, were:

.1 *Integrated Safety Assessment*: accidents revealed flaws in how manufacturers/companies and regulators assessed system risks in the aviation industry. Assumptions about pilot/human behaviour and system failure probabilities were overly optimistic. A more rigorous, holistic safety analysis, including failure modes, human factors, and interface complexity, is essential for assuring safety of complex systems.

.2 *Human Factors and System Transparency*: automated systems must be clearly documented and communicated to operators. MCAS was not disclosed to pilots, nor included in training, which severely limited their ability to respond. This highlights the need for transparent system design, pilot training and intuitive human-machine interfaces which support situational awareness under stress.

.3 *Redundancy and Data Validation*: complex systems must not rely on a single point of failure due to interdependencies in them. MCAS depended on input from one AoA sensor, which led to erroneous activations. Future designs must incorporate redundant sensors and cross-checking logic to ensure data integrity before triggering automated responses.

Complex systems and system integration

32 Whenever there is a discussion on complex systems, there is a struggle to define what complex systems are. The nature of "complex systems" makes this a difficult exercise. Even the definition can range from simple to complex (see annex 1 for more detailed discussion on the definition of "complex systems").

33 For this section, a complex system is a system composed of many components, or subsystems, which interact with each other to collectively result in the emergence of the system behaviour. As noted above, this makes the system behaviour intrinsically difficult to model or predict.

34 Aristotle is quoted as saying: "The whole is more than the sum of its parts".

35 Obtaining the desired emergence to provide functions is why manufacturers and suppliers build systems. Therefore, understanding emergence is extremely important to manufacturers.

36 Complex systems require systems thinking, or System-of-Systems (SoS) thinking. This is looking at the linkages and interactions between the subsystems and/or components.

37 Manufacturers might approach a complex system with the following elements:

.1 systems architecture; and

.2 Model Based Systems Engineering (MBSE).

38 These elements are usually not performed independently. These are performed concurrently, or at least overlapping.

Systems architecture

39 Systems' architecture is the arrangement of entities, or components, organized in a way which supports reasoning about the entities, and describes behaviours and relationships among the entities. Systems' architecture can also be looked at as being the questions asked and decisions made along the way to form the whole of the functions and interactions of the multiple entities.

40 This is where some decisions are made regarding the form and function. Here, the system is identified and the form and function are decided. Then, the system is broken into pieces. Now, the relationships between the pieces can be explored. Finally, the emergent behaviour is determined.

41 There are a lot of tools available that assist with understanding and design decisions. One important tool, or concept, is decomposition. Decomposition involves systematically breaking down a complex system into smaller, more manageable components/elements, beginning with an understanding of the system's intended functions.

42 By first defining the required behaviours and purposes of the system, it becomes possible to identify the structural elements necessary to fulfil those functions.

43 This function-driven approach enables analysis of the relationships and dependencies between components/elements, supporting a clearer understanding of the system architecture at a defined level of abstraction.

44 The decomposition process can be applied iteratively, with each component/element further subdivided to support increasingly detailed examination of both structure and behaviour. This decomposition exercise can be done repeatedly again from a component level to break each of the components into pieces, and so on.

45 The architecture is not just a list. It is not just a decomposition of main functions. The architecture of complex systems is what has to be understood in terms of how the functions are connected. It is part of internal processes and connections, interactions and interrelationships.

46 For marine ships and offshore units, the decomposition starts with the ship as a system of systems, then a breakdown, or list, of systems with an understanding of connections between systems and their interdependencies. Further, decomposition of systems into the structure, hardware, and software is necessary to understand the system and verify and validate systems.

47 When discussing systems' architecture and decomposition, it is natural to focus on machinery systems. However, the consideration of the ship as a system of systems starts with the ship's form and structure. In the case of large machinery, the hull structure and machinery foundation can be highly interdependent. Increasingly, the ship's structure is being monitored, especially in critical locations. One needs to consider that the ship's form and structure is a system which supports and integrates other systems.

48 Decomposition is important and useful for many reasons. For this discussion, decomposition can be used to verify and validate that the intended emergence is achieved as well as verify that class and regulatory concerns are considered appropriately.

49 For manufacturing, one of the obvious factors is producibility. Here again, connections and relationships are important. Dependencies carry over into form and function. Dependencies and relationships of form can drive decisions on manufacturing.

50 There are many methods and tools available which identify relationships of components. The use of these will vary between companies.

51 In addition to these design process elements, there is systems engineering where multiple disciplines work to further the design, integration, management, requirements, documentation, etc. to produce a complex system. Many times, this involves several different manufacturers.

52 Of course, this is just one approach to complex systems by manufacturers. Depending on the product and its complexity, there may be other methods and/or other steps in the process.

The role of classification societies in complex systems

53 Classification societies play a critical role in ensuring that ships and their systems meet defined standards for safety, security and environmental protection through the application of prescriptive rules[8]. However, as the maritime sector evolves into complex, integrated and highly coupled systems, the role of classification must also expand. Nonetheless, there is a need for a more explicit definition and allocation of responsibilities among key maritime stakeholders (such as manufacturers, yards, crew, operating companies, classification societies etc.) across both the newbuild and throughout the lifecycle of the ship. In particular, as incremental hardware and software upgrades are introduced, there is a need to ensure that robust assurance processes and control mechanisms are in place to prevent unintended consequences arising from seemingly minor modifications.

54 Four foundational principles remain relevant:

.1 ensuring effective management of interfaces;

.2 verification of correct operation to ensure safety of function;

.3 assurance of safe and controlled degradation in the event of failure; and

.4 provision for recovery processes which enable restoration of the function to an agreed level.

55 While these principles provide a baseline, they are insufficient on their own to address the unique challenges posed by system-of-systems configurations, data-driven functionalities and software-intensive control architectures.

56 Increasingly, classification societies are being asked to address safety and interoperability not only at the component or system level, but across multi-system interactions which may span ships, shore-based infrastructure and remote operation centres.

57 This shift may require:

.1 verification that adequate interface management is in place during the design, construction, tests and trials, and also during any future system modifications;

.2 evaluation of performance in context, including reliability, responsiveness, and resilience;

.3 adoption of scenario-based testing for fault and operational conditions; and

.4 consideration of digital assurance evidence, such as software conformity, cyber resilience and algorithmic traceability.

58 Complex systems also present challenges in terms of fragmented supply chains. Subsystems are often developed by multiple vendors, tested at different sites and integrated only at a late stage, making end-to-end verification difficult. In response, classification societies should facilitate the development of modular verification strategies, supported by an agreed testing roadmap and structured documentation aligned with a system-level assurance case.

59 Ultimately, the role of classification in this evolving landscape is not simply to verify compliance with static and prescriptive rules, but to contribute to a flexible, lifecycle-oriented framework which supports continuous assurance of safe and effective maritime operation.

Regulations and regulators

60 Regulatory systems rely on science and evidence, coupled with practical operational knowledge of system functions to inform decision making. This current process is not suitable for complex systems which could be making their own decisions.

61 The OECD has published principles of good international regulatory practice which include:

.1 promote innovation; and

.2 be clear, simple, and practical for users.

62 In some situations, particularly for emerging technologies, regulators struggle to keep up with the pace of innovation. As the application of technology rapidly accelerates across geographic and sector boundaries, there is no longer time for the regulatory authorities to reflect, review and test the impact of this technology and to form a consensus on requirements. In those circumstances, the organizations developing the system of systems are typically required to reflect, review and test the integrated system of systems and provide a compelling body of evidence to support the assurance/safety argument.

63 The use of an assurance/safety argument can be described as a goal-based regulatory approach. The use of assurance/safety cases provides greater flexibility in responding to emerging technologies and novel system architectures. The approach allows stakeholders to demonstrate how safety objectives are achieved without relying solely on prescriptive requirements which may not be appropriate for complex or innovative systems. While goal-based regimes have historically required case-specific verification and validation, there is an increasing recognition that elements of the assurance argument, such as evidence patterns, argument structures and assessment criteria, can be standardized and reused across similar applications. This reuse can reduce cost and effort over time, particularly as regulatory familiarity and guidance evolve. Nonetheless, early applications may still require more extensive effort compared to conventional prescriptive regimes, particularly in the absence of established regulatory precedents.

64 Decisions by technology developers are often protected by intellectual property rights making information even harder to come by unless it is required by regulations.

65 Properly applied, digital technology and data may support the sharing of knowledge across national and industry borders.

66 As an example of developing regulations, the principles of Inherently Safe Design and Fault Tolerance are now included within the MASS Code, which was adopted as a non-mandatory code at MSC 111 and should form part of the experience-building phase. This is a significant step in the assurance of complex systems and one that will require a shift in the way these systems are considered from a classification and regulatory perspective to ensure that the compelling body of evidence supports the claim of acceptably safe to operate in a defined context of use. As such, the allocation of responsibilities placed on different maritime stakeholders becomes an important factor and needs to be understood and addressed accordingly.

Future work – directions to consider

67 The increasing complexity of onboard computer-based systems and the need to maintain their security suggests the need for training and certification not only for the crew but for all personnel involved (right from design, construction, operation, maintenance and end-of-life recycling); perhaps even new roles may emerge.

68 Where humans remain a part of the decision-making process, human-centred design must be considered to ensure that the human element is properly addressed. This is particularly important in complex operational environments, with varying levels of automation, workload management and effective response to both routine and emergency situations.

69 A regulatory focus on reducing risk can often lead to an emphasis of focusing on weaknesses and what goes wrong. This can be complemented by "strength-based approaches" where attention is given to learning from acceptable good practices.

70 To unlock the benefits of data in support of overcoming the challenges of safe decarbonization, regulations must support alternative survey methodologies, at least in part by developing mechanisms to encourage data sharing in the maritime industry. As both data analysis and traditional surveys have their strengths and limitations, a combination of both approaches may provide the most comprehensive assessment of a ship's condition, offering alternatives to traditional time-based survey regimes.

71 As ships and their systems become digitally enabled and more connected to shore, off-ship support is expected to become the prevailing operating model for future ships, throughout their lifecycle.

72 Work should start to incorporate "systems thinking" into maritime solutions when managing complexity by defining and incorporating a "system integrator" within maritime regulations, along with guidance on the roles and responsibilities of a system integrator.

Action requested of the Committee

73 The Committee is invited to note the report of the status of work in the JIWG.

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ANNEX 1

Complex systems and novel technologies

1 It is essential that ships which are operated in the future are safe to operate in a defined context of use, fulfilling the expectations of society in terms of safety of life, property and the environment.

2 After a prolonged period of improvement in maritime safety, further gains are proving to be elusive, and yet it is also apparent that society expects better.

3 Against this background we look at the emerging risk and, in particular, the critical importance of a range of issues, including the human element, complexity and the impact of technology change. Additionally, the increasing importance of the lifecycle consideration and the performance of the regulatory framework have also been explored. These facets are all important now, and will all be even more relevant in the ships of the future.

4 The human element has been recognized as a major factor in ship safety by IMO and others for a long time; however, its interaction with increasingly complex and rapidly evolving systems introduces additional challenges which go beyond traditional regulatory considerations.

5 Although there is a general understanding of what a "complex system" stands for, depending on its context, there is no single universal definition when it comes to a "complex system". This is mainly because the characteristics of complexity vary wildly between disciplines, even when one considers it within the maritime industry alone. IEC 63187-1 defines a complex system as:

> "systems where the collective behaviour of their parts entails emergence of properties that can hardly, if not at all, be inferred from properties of the parts."

6 From a maritime perspective, complexity has been created by the adoption of increasingly interlinked, software-intensive systems, to manage the ship efficiently. Complexity has also been created over a long period without deliberate and obvious choice through the increase in the number of organizations and stakeholders who are necessarily involved in ship operation, through a web of links and interactions.

7 The impact on ship safety of change in technology is less obvious, and in some ways it is entwined with the human element and the ability of people to adapt to new technologies. However, the rate of change of technology will continue to be rapid, not least due to the search for responsible actions to deal with challenges posed by global climate change and the demand for improved environmental protection, and these changes will have a major impact on the people who make the industry function, both at sea and on land, throughout the lifecycle of a ship. This rapid pace of change introduces additional risk by reducing the opportunity for operational experience, feedback, and learning to stabilize system performance before further changes are introduced.

8 In parallel, the prevailing regulatory framework, historically based on assumptions of relatively stable technologies and transferable human competence, may no longer be fully aligned with the realities of novel, complex, and software-intensive systems, and can itself become a source of unintended complexity.

9 Complexity is, however, not a single readily discernible characteristic and it comes in a number of forms. For example, complexity can result inadvertently from the employment of multiple layers of sub-suppliers or contributors and a lack of really effective systems integration. In these situations, risks are introduced where:

.1 interfaces between elements of a system are not necessarily well understood;

.2 manuals are available only for components from single suppliers or contributors and not for the complete configured system;

.3 software is just treated as a black box;

.4 validation of performance against an agreed system requirements definition is limited by the lack of time available; and

.5 progressive integration testing and validation is limited by time and cost constraints and the lack of a structured approach to testing and validation against requirements.

10 These issues highlight deficiencies not only in system design, but also in regulatory processes, including integration practices across the ship and its systems lifecycle.

11 Whilst there is no single definition of "system integration", it has been described (context-dependent) in a number of international standards. What makes it challenging is the range of system integration that varies across systems, ranging from "simple" to a more "complex" system-of-systems integration.

12 IACS Unified Requirement E26 (Rev.1) defines "systems integrator" as:

"The specific person or organization responsible for the integration of systems and products provided by suppliers into the system invoked by the requirements in the ship specifications and for providing the integrated system. The systems integrator may also be responsible for integration of systems in the ship. Until vessel delivery, this role shall be taken by the Shipyard unless an alternative organization is specifically contracted/assigned this responsibility."

13 In this emerging landscape it should be recognized that ships equipped with complex systems are likely to be of novel design and the existing skill set may be incompatible to address complex interface management. As part of system integration, the delegation of these interface management responsibilities should be considered right from the outset.

14 The maritime regulatory framework is founded on the basic principle that a crew trained and certificated in accordance with STCW is competent to operate a ship that complies with SOLAS, MARPOL and related standards. There have always been variations between ship designs but the basic technology was relatively universal, and it was not unreasonable to assume that seafarers could be posted to any ship and, after a short period of familiarization, could operate that ship safely. For many years systems were relatively simple and technology was stable, with any changes taking place over extended periods. That situation no longer applies and the industry, and more importantly the regulatory system, must react accordingly, recognizing that the interactions between people and technology will face changes that are often unintended and unforeseen.

15 Moving to the complexity which comes from modern ship design, that complexity can just appear, without any apparent source. Regulatory change can inadvertently cause complexity, perhaps by adding a need for additional sophisticated equipment, such as ballast water treatment plant, or seeking additional functionality. In recent years the merchant shipping community has moved, very quickly, from a tradition of ultra-conservatism to a willingness to embrace innovative and, arguably, underdeveloped solutions. This period has also seen the introduction of new upgrades of existing equipment in such short time scales that there has been little, or even no, experience with one model before the next enters service. This rapid refresh of the technology base is a major challenge to the people who are tasked with operating the ship, both at sea and ashore. Innovation has generally increased complexity, particularly in the chase for improved fuel efficiency, reduced pollution and reduced overall operating cost.

16 Very rarely does innovation deliver a more simple solution that is easier to understand and operate, although it might appear to reduce workloads by extending repair and maintenance intervals or through more sophisticated automation. In general, the adoption of novel technologies or novel uses of existing technologies, which are not supported by a wide industry knowledge and culture, and systems with greater complexity both bring additional risks. In common with the human element issues which are widely discussed, but not necessarily fully understood, these issues must be addressed in a future regulatory system, and within management systems, if the effect is not to be continued stagnation or deterioration in the achieved levels of ship safety, compared to the agreed acceptable level.

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ANNEX 2

Survey results

1 A survey was carried out to gather views on the future of the maritime safety regime, inviting maritime industry stakeholder groups, which resulted in a total of 163 responses, representing shipowners, ship managers, shipyards, designers, flag Administrations, classification societies and equipment suppliers.

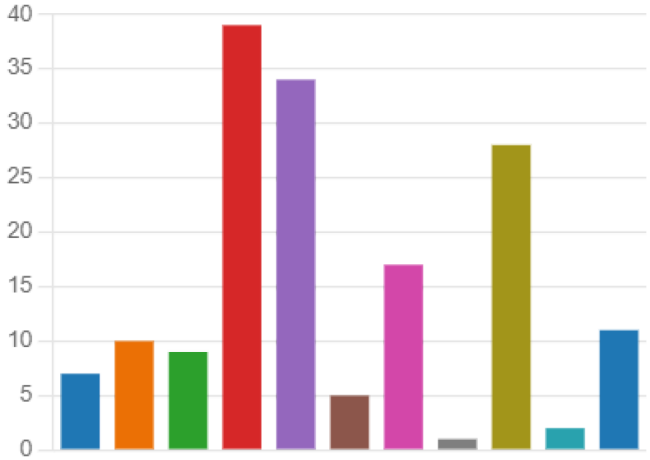
2 Some extracts from the survey results, for ready reference, have been included below.

3 The following survey was completed in 2022; therefore, the results pre-date some of the regulatory changes that are discussed elsewhere in the document. The full survey results are available on the IMODOCS Virtual Portal.

163

Responses

Ship Designer	7
OEM or equipment supplier	10
Shipyard	9
Shipowner	39
Ship Management	34
Maritime Industry Association	5
Maritime Insurance	17
Maritime Finance	1
Classification Society	28
National Authority / Regulator	2
Other	11



Have you / has your organisation encountered any situations were there are no suitable Regulations?

Yes	119
No	43



. As a result of considering the above questions, is there a need for the approach of Statutory Regulations like SOLAS to be changed?

Yes	118
No	45



. In service, would you value alternatives to time-based survey regimes?

Yes	105
No	58



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ANNEX 3

References:

1 Norwegian Safety Investigation Authority (NSIA), "*Report on loss of propulsion and near grounding of Viking Sky, Hustadvika, Norway 23 March 2019"* Marine Report 2024/05, Mar. 2024. [Online]. Available: https://nsia.no/Marine/Published-reports/2024-05. [Accessed: Jul. 23, 2026].

2 International Maritime Organization (IMO), *"Preparing seafarers for the energy transition"* IMO-Media-Centre.[Online].Available: https://www.imo.org/en/mediacentre/hottopics/pages/preparing-seafarers-for-the-energy-transition.aspx . [Accessed: Jul. 23, 2026].

3 Maritime Logistics Academy (MLA), *"Five ways digital technologies are making shipping safer and smarter"* MLA Blog, Jan. 7, 2026. [Online]. Available: https://www.mla.ac.uk/blog/five-ways-digital-technologies-are-making-shipping-safer-and-smarter/. [Accessed: Jul. 23, 2026].

4 CIMAC Digitalization Strategy Group, *"On Enabling the Implementation of a Ship-wide Data Ecosystem"* CIMAC Position Paper, 1st ed., Dec. 2023. [Online]. Available: https://www.cimac.com/cms/upload/CIMAC_DSG_PosPaper_On_Enabling_the_Implementation_of_a_Ship-wide_Data_Ecosystem.pdf . [Accessed: Jul. 23, 2026].

5 CIMAC Working Group 20 (System Integration), *"Digital Twins in the Maritime Industry: Concepts, Definitions, and Applications"* CIMAC Guideline Paper, 1st ed., Apr. 2025. [Online].Available: https://www.cimac.com/cms/upload/workinggroups/WG20/CIMAC_WG20_2025_Guideline_Digital_Twins_in_the_Maritime_Industry.pdf. [Accessed: Jul. 23, 2026].

6. Federal Bureau of Maritime Casualty Investigation (BSU), *"Investigation Report 405/20: Less Serious Marine Casualty, Allision with a Quay Wall by the Tanker NORTHSEA RATIONAL in Hamburg on 25 November 2020"* Federal Bureau of Maritime Casualty Investigation, Hamburg, Germany, Investigation Report 405/20, Nov. 25, 2021. [Online]. Available:https://www.bsubund.de/SharedDocs/pdf/EN/Investigation_Report/2021/Investigation_Report_405_20.pdf . [Accessed: Jul. 23, 2026].

7 Bahamas Maritime Authority (BMA), *"Report of the Marine Safety Investigation into a Boiler Explosion Leading to Three Fatalities on Board the Drill Ship Norbe VIII on 09 June 2017"* MarineSafetyInvestigationReport,Mar.18,2020.[Online].Available: https://www.bahamasmaritime.com/wp-content/uploads/2020/10/BMA-Investigation-Report-Boiler-explosion-resulting-in-three-fatalities-onboard-the-Norbe-VIII.pdf . [Accessed: Jul. 23, 2026].

8 International Association of Classification Societies (IACS), *"Classification Societies – What, Why and How?"*, London, U.K.: IACS, Nov. 2023. [Online]. Available: https://iacs.org.uk/membership/role-of-class. [Accessed: Jul. 24, 2026].