DNV·GL

CLOSING THE SAFETY GAP IN AN ERA OF TRANSFORMATION

WHITE PAPER

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1 Executive summary

The maritime industry needs a safe and efficient path through the complexity associated with developments involved in digitalization and decarbonization. Defining this path is possible 'with foresight and a clear vision', according to DNV GL's Maritime Forecast to 2050.[1] Foresight indicates that the success or failure of potentially transformational digitalization and decarbonization efforts hinges on the answer to the question: how capable is the industry of recognizing and managing the associated safety risks?

Based on decades of relevant assistance to the industry, DNV GL aims to be a trusted voice to safeguard a maritime industry transforming rapidly to meet its digitalization and decarbonization ambitions.

This white paper aims to spark a discussion to make safety-related risks ('safety hurdles') easier to identify and manage. This leads the way to closing gaps between today's safety levels and the quality of risk management that is essential for the successful transformation to a more digitally-smart and carbon-neutral future. We present a broad overview of safety-related risks, which the industry may use as a foundation for making sound decisions for safeguarding maritime operations during transformations in digitalization and decarbonization.

Holistic management of human, organizational and technical factors
For this paper, we consider safety in maritime to be an emergent property of a system's robustness, resilience, and ability to continuously improve. We argue that holistic risk management, including a systemic perspective on safety, is key to managing safety hurdles on route to a more digitalized, carbon-neutral industry. Barrier management as a tool will help to identify the risk controls necessary to facilitate human, organizational, and technical capabilities, and to counter their limitations. This is what is needed to safeguard maritime operations through this era of transformation.

Digitalization increases system complexity and introduces new ways of operation and collaboration. We foresee that traditional risk management methods will be insufficient for the new complexity, and that centralized and dispersed teams will change how people work as organizations become a patchwork of multiple stakeholders. Safety in an increasingly digitalized maritime industry will therefore benefit from: system integration to manage systems' complexity; addressing the needs of the human element in a digital environment; and, digital transformation strategies for how organizations should manage emerging new risks.

Decarbonization involves alternative fuels and operations with new safety-related risks. These include safety hurdles related to stakeholders working in silos with a focus on subsystems, a regulatory framework that cannot match the pace of technological development, and suppliers and end users that lack maritime and fuel-specific competence. Maritime operations in an increasingly carbon-neutral industry can be better safeguarded through collaboration and transparency; collective commitment to contribute with knowledge and experience to supplement missing regulations; and through specific competence development and a culture of continuous learning to help drive forward knowledge and experience.

DNV GL is involved in all these areas as a key stakeholder, a provider of assurance, a thought leader, and as a partner to help the industry close gaps between the current safety-risk picture and maritime's ambitions to transform itself through digitalization and decarbonization.

People play a key part in safe transformations
We conclude that focusing on the complexity of innovative technology for digital transformation and decarbonization is central, but not enough to achieve and maintain smarter and carbon-neutral shipping. Successful transformations depend also on people's creativity, problem-solving ability, and resourcefulness. To reap the benefits of this era of transformations, the industry stakeholders need to collaborate from the beginning to the end of a ship's life cycle. Their aim should be to create a shared focus on design and operations that support people's performance. Every maritime organization can play a part in facilitating safe and efficient performance by balancing out function allocation between technology and people, considering human-centred design of systems, and ensuring the physical, mental, and social wellbeing of the people. This is what will put the industry in the best position to transform itself through digitalization and decarbonization.

1) DNV GL, 2020. Maritime Forecast to 2050. https://eto.dnvgl.com/2020/index.html

2 Introduction

With all eyes focused on transformations in digitalization and decarbonization, we as an industry need to commit ourselves as much to safety as to transformation. After all, the safe and timely transition towards a digitally smart and carbon-neutral future may be compromised if the safety-related risks that these transitions bring about are not accounted for.

The maritime industry has shown it is capable of continuously transforming itself to improve efficiency and productivity, irrespective of challenges along the way. One major transformation is through digitalization catalysing wider use of data, data-driven models, and remote services in shipping, leading to improvements in efficiency and productivity. The industry is also dedicated to finding a pathway towards decarbonization. Digital transformation enables innovation in decarbonization as digital technologies are leveraged to meet sustainability goals. Efforts to apply innovative digital solutions and reach decarbonization goals in the crisis reflect stakeholders' commitment to UN Sustainable Development Goals (Figure 2-1). These efforts showcase maritime stakeholder ambitions to put themselves in competitive positions, with vessels that are 'smarter' than ever before.

But we also need to make the new and more complex risk picture, emerging with innovation and transformation, more explicit so that we can better manage it and put proper risk controls in place. Focusing on the complexity of innovative technology is central, but insufficient in isolation to achieve and maintain transformations towards smarter and decarbonized shipping. The success of these transformations also depends on people. Therefore, we must understand what people require to be able to exercise their creative, constructive, and problem-solving abilities, which are necessary to safeguard maritime operations throughout these transformations.

This is where we as an industry can and should work together to be proactive and prevent adverse events from happening and potentially stalling transformations in digitalization and decarbonization. As stated in DNV GL's Maritime Forecast to 2050: 'Even in these extraordinary times, we must make practical and sound decisions today while still looking ahead and finding the innovations that fuel our journey forward.' This white paper presents a broad overview of safety-related risks which we as an industry can use as a foundation for making informed decisions along the way to smarter and carbon-neutral shipping.

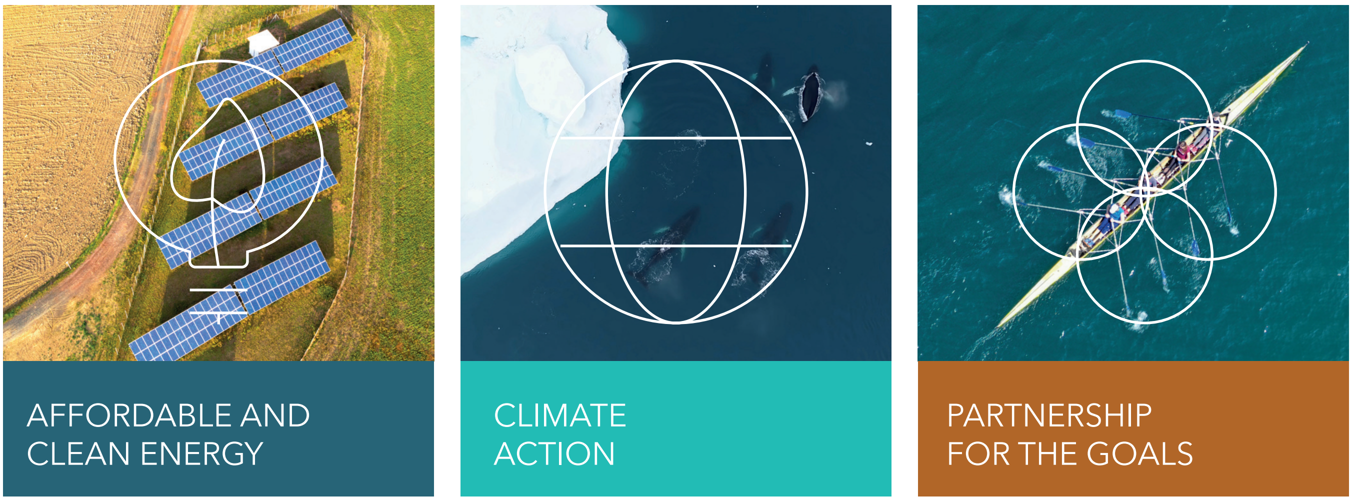


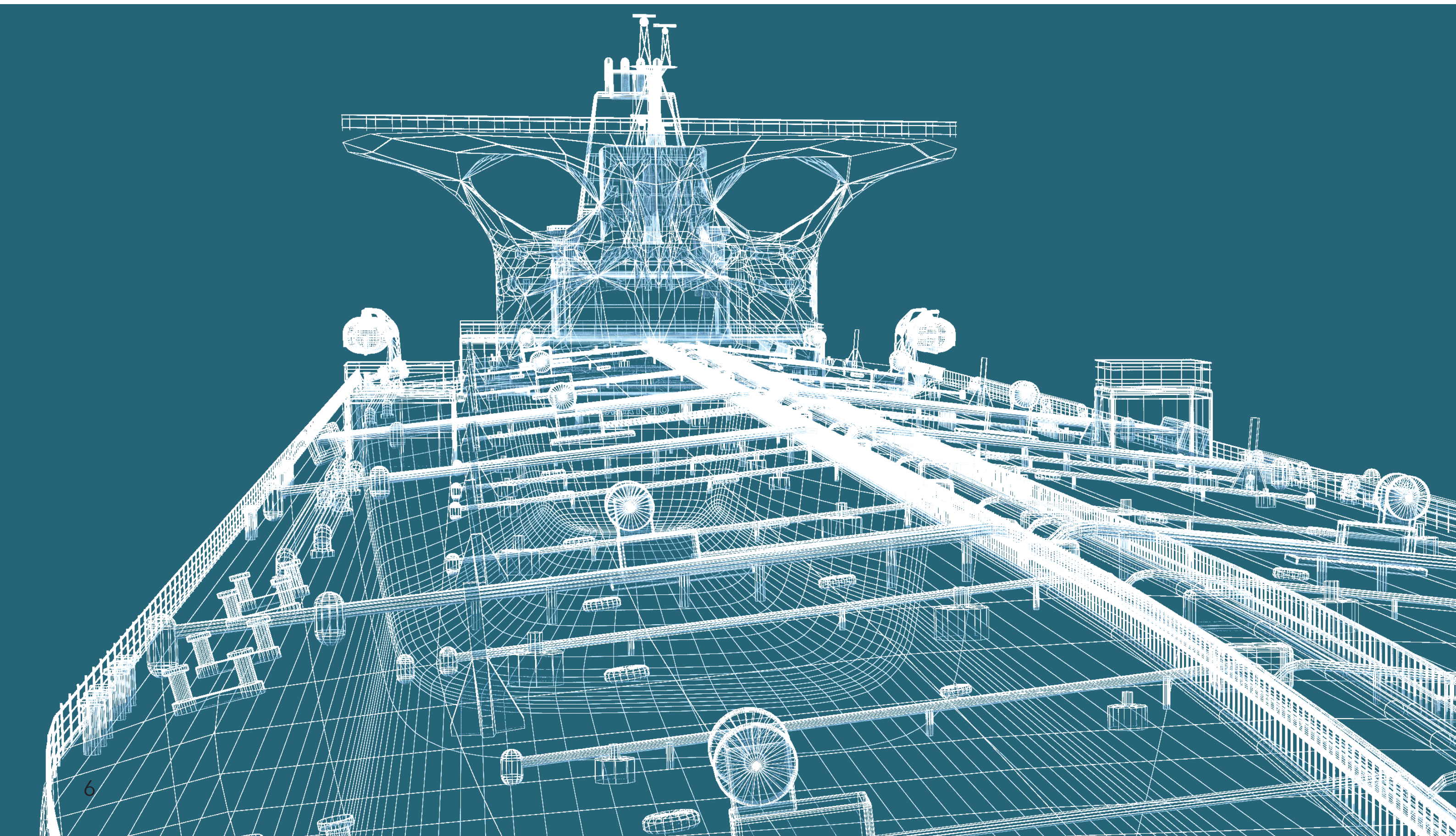
Figure 2-1: Three UN Sustainable Development Goals that digital transformation and decarbonization in the maritime industry contribute to

3 Purpose of the white paper

With this paper we aim to provide guidance to maritime stakeholders for controlling and mitigating safety risks related to transformations in digitalization and decarbonization. This will leave you in a better position to take informed decisions about how to achieve and maintain smarter and carbon-neutral shipping.

With this paper, we want to encourage the industry to strengthen its robustness and resilience by putting safety on top of the agenda throughout this era of transformations. Moreover, we encourage all stakeholders to implement processes for continuous improvement, driven by the urge to learn, share, and improve.

As DNV GL's Maritime Forecast to 2050 concludes: 'With foresight and a clear vision, there can be a path through complexity connected to [the COVID-19 pandemic and] technological development.' This white paper complements this vision with a focus on safety. The content should make it easier for stakeholders to identify and manage safety-related risks that the industry will need to address as it transforms itself to become more digitalized and decarbonized. As such, DNV GL aims to be a trusted voice to safeguard a maritime industry rapidly transforming to meet its digitalization and decarbonization ambitions.



4 Scope and key concepts

In order to find a safe and efficient path through the transformations described, this paper aims to spark discussion about safety-related risks and mitigating measures in the context of maritime digital transformation and decarbonization.

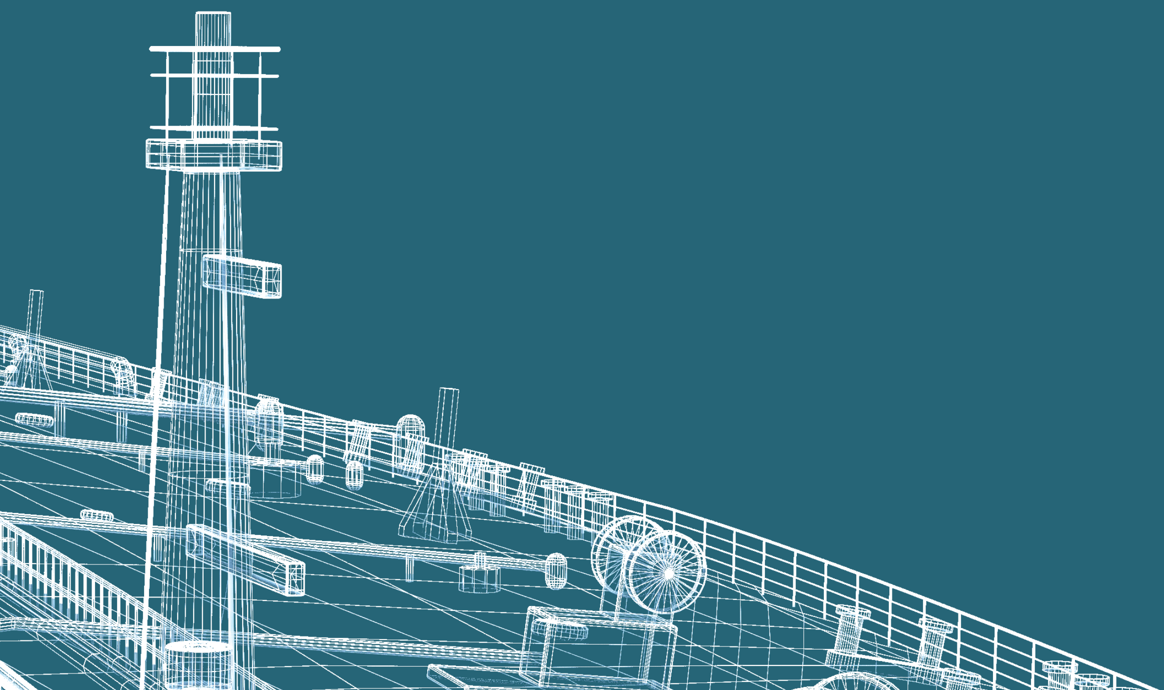
The paper discusses digital transformation and decarbonization in two separate chapters to highlight the safety risks ('safety hurdles') that exist outside of the intersection between these transformations.

The paper covers an outlook of approximately five years. We expect this to be a period characterized by the iterative development and implementation of rules and regulations as the industry rapidly evolves to using more interconnected digital systems and technology, and to performing vessel operations with reduced carbon emissions.

We do not explicitly differentiate between vessels in operation and newbuilds. This is because the discussion is, with some exceptions, relevant to all stages in a vessel's life cycle.

It is well understood that cost is the major driver for many decision makers in the maritime industry. However, this paper leaves cost out of its scope, primarily to facilitate unrestricted discussion about risks and opportunities related to safety and the transformations. The paper puts safety at the top of the agenda and urges readers to consider the arguments as content for a transparent, reasoned, and informed cost-benefit analysis.

In what follows, we explain our understanding of three key themes covered in this paper: safety, digital transformation, and sustainability and decarbonization.



4.1 Safety

At its core, this white paper is about safety. We choose to define safety as an emergent property of maritime systems that are robust, resilient, and have a process in place for continuous improvement (Figure 4-1). Safety as an emergent property means it is greater than the sum of its parts.[2] A system is considered to be a set of human, organizational, and/or technical elements that can achieve things together that each component part cannot accomplish alone.[3]

What do we mean by a 'robust' maritime system?
A robust system here is one that builds on years of developing competence and accumulating experience to contribute to the development of regulations, rules, and standards for building and operating safe maritime systems. Robustness also has a flexibility component enabling the system to react to foreseen events in a pre-planned manner. Actual and de facto regulatory entities such as the International Maritime Organization (IMO), flag states, port state control, insurance companies and classification societies oversee and set requirements to maintain the quality expected of acceptable safety levels.

What do we mean by a 'resilient' maritime system?
The maritime industry builds on a proud history of seamanship, which is synonymous with coping with change through agility. Rapid developments in society create new opportunities and challenges in the maritime industry, and agility will be a prerequisite for safety. The pace of development challenges existing rules, regulations, and standards, thus requiring different approaches from the industry to ensure equivalent or higher safety levels for maritime systems. To respond to the industry's needs, regulators have to assure quality in the process of considering the relative safety levels of new and familiar systems. Technology development is a main driver of the rapid developments in the industry. Besides the focus on technology, we also need to acknowledge and subsequently support people's ability to solve problems and adapt to unfamiliar situations. People's roles within the industry are changing, but they will continue to be essential contributors to safe maritime operations in the future.

What do we mean by 'continuous improvement'?
Although a maritime system can appear safe at a given time, it must remain safe from one moment to another, and over time. It therefore needs mechanisms that allow it to keep improving so that it can update and change what is protecting the vessel now so that it can meet similar or new threats in the future. Lessons learned are fed back into the robustness of the system, while any improvements to mechanisms for adapting to changing threats feed back into the resilience of the system. These lessons and mechanisms are dependent on how much the system benefits from feedback from events with positive or negative outcomes. Maritime systems that embrace a culture of learning also benefit from 'creative worry', where people's sense of unease allows them to think and act on what could happen next. This fosters a proactive approach to safety.

Taken together, the safety of maritime systems relies on a systemic perspective of safety. This is about the constructive interaction between 'HOT' (human, organizational, and technical) elements which together create robust, resilient systems that are capable of continuous improvement. There can be no guarantee that the safety-risk picture is complete if any 'HOT' element is left out of a discussion about what contributes to safeguarding maritime operations.

2) DNV GL, 2019. White Paper–Safety Assurance of Complex Systems, Part 1: Complexity.
3) Ibid.

Interactions and properties of a safe maritime system

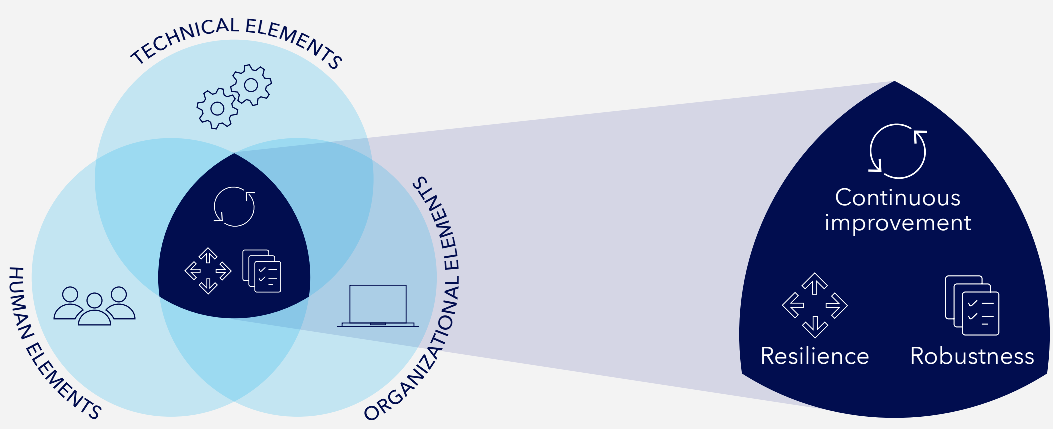


Figure 4-1: Safety described as an emergent property of the interaction between human, organizational, and technical elements that together create robust, resilient systems that are capable of continuous improvement.

4.2 Digital transformation

From providing support for simple tasks to becoming an integral part of our systems, technology has gradually become an integrated part of our life. The term 'digitalization' embraces a wide perspective on the technological developments that are trending. 'Digital transformations' refers to societal changes caused by digitalization. Here, this covers transformations experienced on board vessels and onshore in ship management. It may be argued that digital transformation is more about people than digital technology.

Recent digital transformations in maritime have been driven by increased connectivity, emerging technologies (e.g. big data, Internet of Things, autonomous systems, data management, automation) and centralization.[4] The changes that are part of this digital transformation underlie the ambition to establish 'smart shipping'. There is, however, no unified definition of how extensive the transformation needs to be, or how 'smart' the vessel must be. Digital transformation can thus equally well refer to minor changes to an individual vessel, or to a comprehensive shift in the maritime industry.

Digitalization has been taking place for many years. However, the more recent digital transformation is the result of emerging new technologies coupled with greater satellite coverage and reduced data-transfer costs, enabling shipowners to capitalize on vessel data. This is a driver for reducing cost and fuel consumption, and for increasing efficiency and safety.

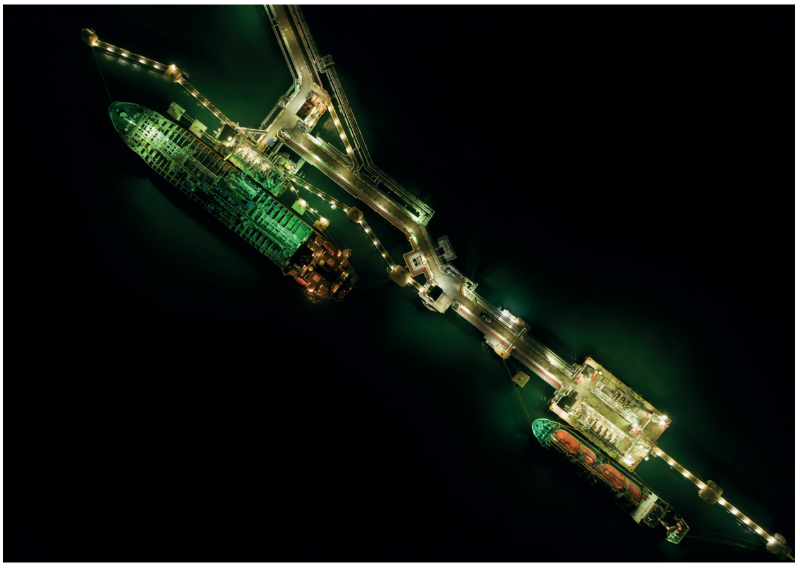
Digital transformation has disruptive properties that offer new opportunities. Yet the digital transformation is also part of the gradual evolution that comes from technological development. Digitalization is generally not a goal in itself, but a means to achieve other goals. The maritime industry should therefore explore the risks and opportunities connected to change through digitalization to see how digital transformation can best contribute to safer, more sustainable operations.

4.3 Sustainability and decarbonization

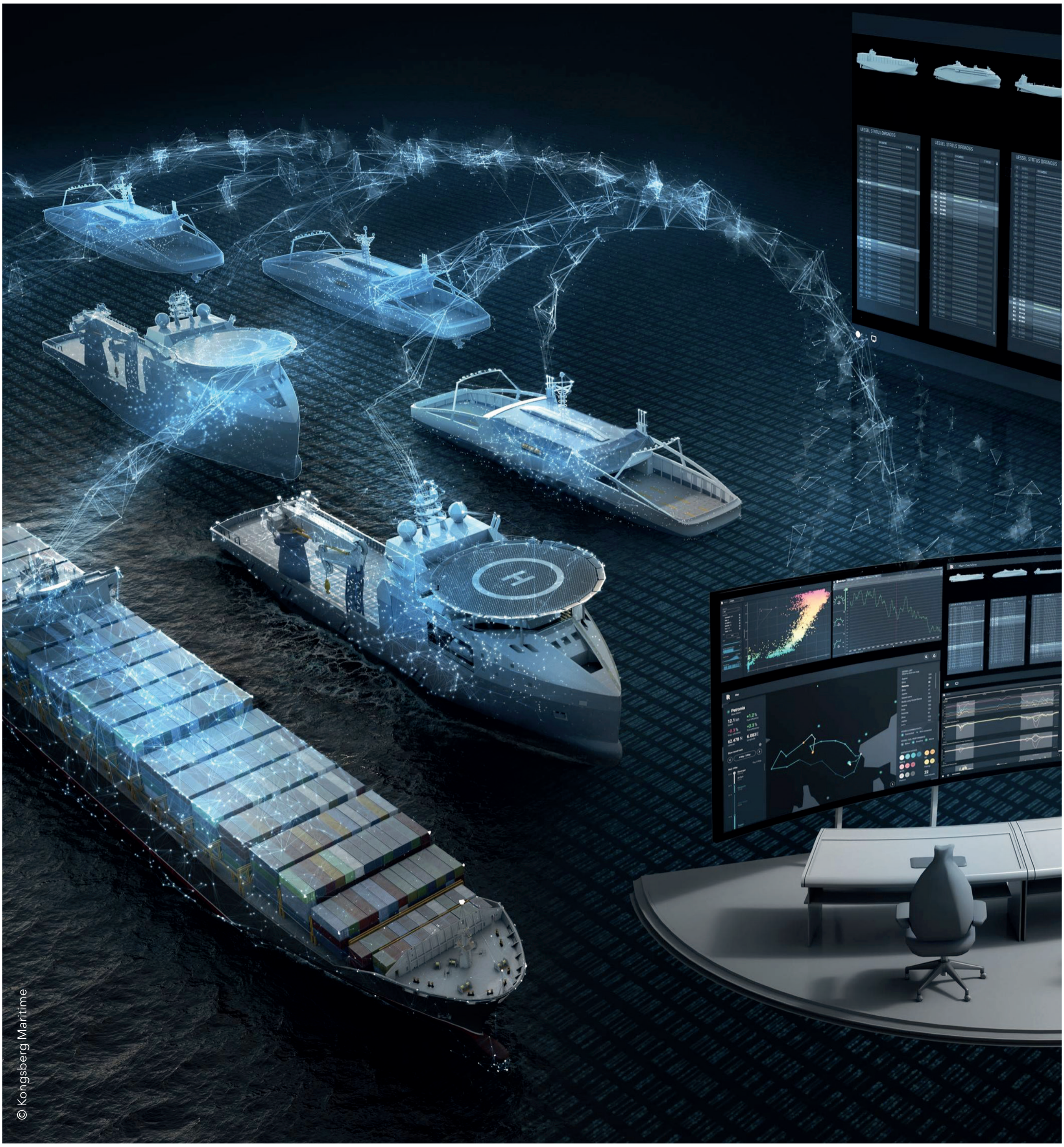
Seventeen Sustainable Development Goals (SDGs) lie at the heart of the 2030 Agenda for Sustainable Development adopted by the UN in 2015. They are an urgent call for action in a global partnership. DNV GL is committed to contributing to the SDGs, as reflected in our purpose, our vision, and our values.

In support of SDG 13 (climate action), the IMO has adopted mandatory measures to at least halve greenhouse gas (GHG) emissions from international shipping by 2050, an ambition that also aligns with the Paris Agreement global warming mitigation goals. The maritime industry is dedicated to developing new technology and alternative carbon-neutral fuels to achieve the IMO goals. These are also the only practical ways for shipping to achieve the IMO's ultimate vision of full decarbonization as soon as possible before 2100. These requirements for an energy transition in maritime challenge the industry to innovate and follow through with implementation.

In this paper, the term 'sustainability' is used to cover all the measures that the maritime industry is putting in place to combat climate change for a sustainable future. We focus more on the term 'decarbonization' specifically to describe the pathway that the industry is following as it implements carbon-neutral fuels, adopts new technology and systems, and introduces alternative modes of operation to reduce GHG emissions.



4) DNV GL, 2020. Technology Outlook. www.dnvgl.com/to2030



5 Safety and digitalization

While technology developers stress the benefits of digital transformation, it is just as important to understand that the transformation also affects the risk picture for the maritime industry.

Digitalization can play an important role in maintaining high performance in new and challenging situations. During the COVID-19 pandemic, for example, the industry has swiftly adopted digital solutions to enhance safety, efficiency, and sustainability. This experience has proved that digitalization has the potential to increase the utilization of assets; improve energy efficiency; enhance condition and performance monitoring of vessels, equipment, and cargo; and, to reduce the presence of people in dangerous and hostile environments.

However, the industry's experience with implementing new technologies shows that focusing on technology alone is too one-sided to get a complete view of all the safety-related risks and opportunities. For digital transformation in maritime to continue to succeed over time, its stakeholders must therefore consider the interactions between technology, human cognition and behaviour, and organizational influences.

5.1 Safety hurdles throughout digital transformation

With digital transformation comes digital risk; the system becomes more complex, with emergent properties that require attention. Traditional risk management methods can become inadequate, and different methods are needed for making risks explicit and for identifying mitigating measures. Although digitalization is technology driven, the digital future relies on our understanding of the interacting roles of people and technology. Finally, managing risks in digital transformation requires a proactive approach from organizations. This raises the need for a digital transformation strategy for coping with emerging risks.

In the following sections we discuss several safety hurdles that can impair safe maritime operations in a digital transformation. We also highlight how efforts to uphold safety throughout digital transformation can draw on experience with challenges in automation, and should plan for the journey to develop innovative digital solutions.

5.1.1 Managing complexity for successful transformation

The increased complexity that digitalization contributes to a system is an inherent challenge of digital transformation. While digitalization can replace manual tasks with technology, it also creates more distance between a person and the operation. This influences people's ability to understand, monitor, and predict the system's performance. At the same time, interconnected software, sensors, and machines with control systems dependent on algorithms, can be susceptible to interrupted communication and underperformance, and may also exhibit sub-standard human-machine interfaces.[5] Systems become more vulnerable to new failure modes that result from more complex interactions between digital technologies and between such technologies, people, and organizations. Cyber security threats add another layer of risk to safety.[6] The more the complexity within and between systems increases, the more challenging it becomes for people to predict an outcome and act appropriately.

Silos reduce collaboration between maritime stakeholders, and add to the complexity. The maritime industry uses many industrial platforms that have limited standardized interfaces. The responsibility for the integrated software systems is spread across vendors and sub-suppliers. This lack of system integration, and the general lack of a holistic risk understanding, make it a struggle to manage the design, construction, operation and maintenance of a software-controlled vessel. It also makes it more difficult to re-use digital models and apply them more broadly for diagnostics, prediction, and assurance.

Barrier management for enhanced risk control

Making risks more explicit is one way to better grasp the holistic risk picture and incentivize stakeholder collaboration. Barrier management has been tried and tested in other industries. It offers the maritime sector a promising approach to plan and monitor how the safety of operations is influenced as contexts change. Barrier management provides a holistic approach to collecting and consolidating

5) DNV GL, 2016. Position Paper–Understanding Sensor Systems Reliability.
6) DNV GL Cyber Secure Class Notation, 2018.

information about threats, consequences, and the need for risk controls. This generates more complete and up-to-date decision-support tools for identifying the barriers and safeguards that need to be in place to prevent and mitigate adverse events. This, in turn, helps to identify which stakeholder is responsible for what, incentivizing stakeholders to work together to reduce overall risk.

Risk and safety barrier management

DNV GL's Synergi Life software offers a digital way to dynamically track the performance and integrity of safety barriers. It also provides data-based insight for decision support to maintain stable and safe operations.[7]

Meeting requirements for safety equivalence

Regulatory bodies often require new technology to be as safe or safer than existing technology. Proving such a level of safety can be difficult, and there are several potential pitfalls along the way. One common but insufficient response to this requirement has been to reframe the question into one that addresses component reliability. In simple mechanical systems, where the failure of a component is the precondition for a system to enter a hazardous state, safety can be assessed by verifying the reliability of the component. Applying this mindset to complex systems, safety would then be measured at a component level and through an evaluation of whether the software is performing its specified, required, or intended functions. However, this mindset ignores the idea that safety is an emergent property of the entire system, meaning that something greater than the sum of the parts is what makes systems safer.[8] In addition, an unreliable system may be safe, and a reliable system may be unsafe; so, safety cannot be concluded from a body of evidence that only demonstrates adequate reliability (Figure 5-1).

The maritime industry currently has no formal method or toolset for including system complexity in the overall risk picture in a rational way. At the same time, safety regulations are starting to lag behind the accelerating digital developments. Consequently, new technologies and systems may be introduced without relevant standards for verification and testing in place to prove equivalent safety.

DNV GL's class notation for Enhanced System Verification (ESV)[9], including services related to Hardware in the Loop (HIL) testing, and Integrated Software Dependent Systems (ISDS) class notation[10] are examples of initiatives that promote testing and verification throughout the system life cycle to ensure that complex systems work together when they are needed the most. Also, DNV GL's digital features rules for ship classification which entered into force on 1 January 2021 address this challenge by providing a framework for assessing and visualizing digital features of vessels.[11] This offers stakeholders a platform for demonstrating cutting-edge technologies and unlocking the value that is brought to the market.

Verification methods for future systems should be based on a 'systemic' perspective on safety. A systemic perspective appreciates that, to understand systems, we must realize that they consist of people, organizations, and technology

7) Synergi Life–Barrier Management module. https://www.dnvgl.no/news/dnv-gl-offers-a-step-change-barrier-management-solution-through-synergi-life-qhse-software-48787
8) DNV GL, 2019. White Paper–Safety Assurance of Complex Systems Part 1: Complexity. www.dnvgl.com/publications/safety-assurance-of-complex-systems-part-1-complexity-165015
9) https://rules.dnvgl.com/docs/pdf/dnvgl/ru-ship/2017-01/DNVGL-RU-SHIP-Pt6Ch5.pdf, Section 13
10) https://www.dnvgl.com/services/isds-class-notation-74225
11) DNVGL-RU-SHIP Pt.6 Chapter 11: Digital Features. https://standards.dnvgl.com/explorer/document/79E5C15F1E15498B9434650D35A16745/2

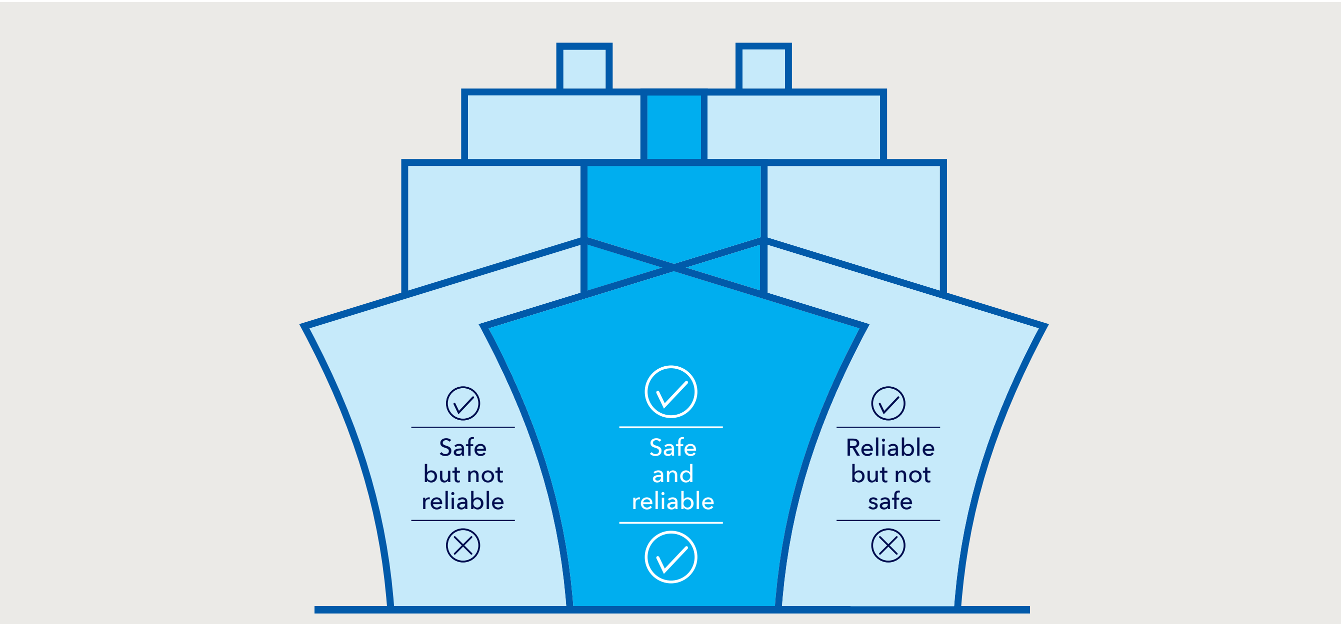


Figure 5-1: Safety and reliability in complex software-intensive systems, showing that information about reliability alone cannot lead to conclusions about the safety of a system. Concept reproduced from DNV GL's White Paper – Safety Assurance of Complex Systems.

that are all related to each other and their environment. This means that safety emerges from the interaction between the human and technical elements, and organizational processes, and not from the behaviour of just one of these elements.[12] In order to address each of these elements properly and consistently through a system's life cycle, it is essential that they are included as early in the design and engineering phases as possible. Close collaboration throughout the entire life cycle will also facilitate system integration. The need for system integration early in design is highlighted in DNV GL's SRtP[13] and DYNPOS[14] class notations.

Safety assessments should generate evidence for safety through product and process verification. Simulations can help to test and verify the safety levels of a system without creating risk to life, property, and the environment. One way to conduct product and process verifications is by using digital twins. These virtual images of an asset are based on all information available about the asset, including dynamic updates on condition and operational parameters.[15] As exemplified in the Open Simulation Platform joint industry project (JIP), the use of digital twins is a cost-effective approach to support the design and operations of future maritime systems.[16]

5.1.2 The human element is key

The digital transformation will lead to two changes in how maritime operations are carried out. First, functions will be more centralized. With increased connectivity, and as technology continues to mature, we foresee more functions currently carried out on vessels being moved ashore. Second, we expect to see more 'dispersed teams' as functions currently performed at one location are allocated instead to team members in different places. The decision to operate through centralized or dispersed teams can depend on the need and availability of specific knowledge and experience connected, for example, to local areas of operation and/or to specific types of vessels or systems.

It is likely that organizations may need to combine the centralization of functions across vessels with teams dispersed between vessels and shore. This brings about change to traditional ways of working. It may raise questions about, for example, responsibility, accountability, communication needs or competence requirements. The successful combination of centralization and dispersion of teams therefore depends on solid understanding of the role of the human element in the digital future. This calls for a structured function-allocation process and a human-centred focus in design.

What do we mean by 'function allocation'?

For decades, the development of automation in the maritime industry has been about technology replacing the human, assuming that less human involvement can benefit safety. Technology may, for example, reduce exposure to dangerous situations, or lessen human involvement in repetitive tasks, for which humans are known to be poor performers. However, using more technology does not necessarily lead to a reduction in human error. Rather, despite the impressive capabilities that technological solutions provide to future systems, it is just as important to realize how the human element can compensate for technological limitations. Technology excels in stable performance over time and in delivering accurate responses to known challenges. People are superior in adapting to unknown challenges and using all available means, including technology, to cope with situations in creative ways.

Function allocation is about the distribution of functions between technology and people. It is particularly important throughout digital transformation because there are potentially fewer people available to intervene if the design of the system does not meet safety requirements, or if the system does not work as intended. High-performance systems ensure optimal performance by considering the strengths and weaknesses of both the human and technical elements in a dynamic function-allocation process.

Function allocation should be performed both for specific tasks and higher-level operations such as navigation, cargo loading, and bunkering. The allocation must consider that the assigned agent – a person or technology – should be capable of not just performing the assigned function but also the sum of all assigned functions. Moreover, the agent should be able to integrate functions and manage the required dynamics in operation. As such, the function allocation must be the result of a deliberate design decision.[17] In this way, the function-allocation process underlines the interaction between people and technology, and feeds into an overall understanding of the human, organizational, and technical elements that influence the holistic risk picture.

Function allocation in design for vessel autonomy

Function allocation in digital transformation requires competence about how digitalization can affect the successful allocation of functions. DNV GL has been working with the European Maritime Safety Agency (EMSA)[18] to identify emerging risks and regulatory gaps related to the implementation of different degrees of autonomy in vessels. One element of the work has been to describe how functions should be allocated between the operator and the system, followed by a risk analysis to evaluate the safety of the solution.

12) DNV GL, 2019. White Paper-Safety Assurance of Complex Systems, Part 1: Complexity.
13) https://rules.dnvgl.com/docs/pdf/DNVGL/CG/2019-07/DNVGL-CG-0004.pdf
14) https://rules.dnvgl.com/docs/pdf/DNVGL/RU-SHIP/2015-10/DNVGL-RU-SHIP-Pt6Ch3.pdf
15) www.dnvgl.com/article/making-your-asset-smarter-with-the-digital-twin-63328
16) www.opensimulationplatform.com
17) Pritchett, A., et al. 2014. Modeling Human-Automation Function Allocation. J. Cognitive Eng. and Decision Making, 8(1), 33-51.
18) www.emsa.europa.eu/mass.html

Taking a human-centred focus in design
People will always play a role in the outcome of system performance, whether they are operating equipment, maintaining hardware, writing new procedures, or designing new technology. Focusing solely on technology in the development of future maritime systems will not help to understand the human contribution to successful system performance. Nor will it help to identify risk controls that need to be in place to support human performance and prevent human error. This is where the need for human-centred design becomes apparent.

Human-centred design is a well-documented process for developing systems with technologies that support human performance.[19] This ensures that:

- the design is based on an explicit understanding of users, tasks, and environment;
- users are involved throughout the design and development phase;
- the design is driven and refined by human-centred evaluation;
- the design process is iterative;
- the design team includes multidisciplinary skills and perspectives; and,
- the design addresses the whole user experience.

19) ISO 9241-210: 2010. Ergonomics of human-system interaction. Part 210: Human-centred design for interactive systems.

As an example, sensors can provide useful and real-time feedback about the system's state[20], but there still tends to be a gap between how technology is designed and intended to be used, and how it is implemented and used in practice. This gap needs to be made explicit so that it can be discussed among owners, suppliers, rule developers and authorities. Owners, suppliers, and rule developers can benefit from such operational feedback for the purpose of learning and redesigning systems and requirements. This (iterative) process of learning and redesign will add to their ability to create human-centred designs and to set up-to-date standards more relevant to operation[21]. End-user insights into what does or does not work in practice are essential building blocks for continuous learning among all stakeholders, from crew and contractors on board to local and international authorities.

→ Industry project raises holistic understanding of risk

DNV GL's JIP on human-centred design of alert management systems addressed challenges related to alarm flooding on the bridge. One of the main conclusions that the JIP consortium agreed upon was the need for system integration and human-centred design to provide the operator with the necessary decision support.[22]

Discussions about autonomous vessels highlight the paradox that autonomy must have a human fallback. As autonomy increases, so does the challenge of human-machine interaction. The industry is considering levels of automation on the pathway to autonomous shipping. One such level assigns responsibility for making operational decisions to a human operator located remotely. Apart from possible issues with connectivity, this introduces the challenge of designing technology and infrastructure that can provide the remote operator with the necessary information for situation awareness. It also introduces risks related to keeping the human in the loop. For example, decision making that is more technology-driven will make an operator passive, which does not support the operator in preparing to be ready to take over the operation if needed. The iterative process of human-centred design will be key in the development of autonomous solutions because it will highlight what the end user needs (e.g. communication and information requirements, human-machine interface) to be able to perform (remote) tasks safely and effectively.

Taken together, as more digital solutions are introduced, the role of the human element in assuring safety tends to move into the background. The human element cannot be completely eliminated from the equation, however. Hence, it is now even more important to follow a human-centred design process to make the factors that influence human performance more apparent. This will help to better support the strengths and mitigate weaknesses of the human element alongside technical and organizational factors in an operation.

5.1.3 Why you need a strategy for digital transformation

Digitalization enables risk management but is itself a risk that needs managing as part of the changing risk profile that organizations will face in the future. For example, the structure of a traditional organization can change. Digitalization can then create opportunities for using more suppliers to deliver operational functions. This may be the case when a control room is designed to manage several vessels, potentially from different organizations. Such a concept has several upsides, such as the specialization of operators, reductions in cost, benchmarking, and performance optimization. Still, various risks need to be considered when organizations start to become the sum of a dispersed team of suppliers. Such risks are, for example, related to the responsibility of integrating organizational processes across various suppliers; the challenge of developing a culture that supports the system's safety; and to having to meet expectations about competence development.

An organization has the unique ability and responsibility to manage risk throughout the digital transformation. Organizations can initiate processes for continuous improvement that facilitate learning and development in the organization. Exchanging experience with the purpose of learning also lays the foundation for more resilient maritime operations. The competence and experience of robust maritime operations need to be adjusted and adapted to new (safety-related) experiences. For example, what is known about safety risks associated with today's digital systems needs adjusting and adapting to meet each new experience fed back in from the field. This ability to adapt is key to maintaining the momentum in developments in digitalization.

To adapt to change and manage associated risks to organizations, those aiming to embrace the opportunities that digital transformation offers need a **digital transformation strategy**. A digital strategy should:

- discuss the digital ambitions and opportunities that the organization is aiming for;
- support the overarching strategic company goals including, for example, reducing operational expenditure and fuel use;
- explain how digital transformations can support the organization in reaching these goals; and
- cover what technologies and data requirements the organization will need to meet these goals.

At its core, the digital strategy should include a process for managing the changes brought about through the transformation. The process should also include a requirement to revisit the strategy frequently to keep up with the pace of technological development.

20) DNV GL, 2019. White Paper–Safety Assurance of Complex Systems, Part 2: Assurance and analysis.
21) https://rules.dnvgl.com/docs/pdf/DNVGL/RU-SHIP/2015-10/DNVGL-RU-SHIP-Pt6Ch3.pdf, Section 5
22) DNV GL, 2016. Human-centred design of alert management systems on the bridge. Report 2016-1147, Rev. 1.

6 Safety and decarbonization

For the transition to zero-carbon emissions to succeed, we as an industry must establish a robust foundation of competence and experience that will enable and maintain safe uptake and use of new technology and alternative fuels.

Yards, suppliers, and shipping companies continuously strive to create innovative vessel designs, new technologies, and more efficient systems to reduce carbon footprints and support the uptake of alternative fuels in order to meet IMO GHG emission-reduction goals by 2050.

At the same time, regulatory bodies need to keep ahead of the game to ensure level playing fields and specify at least a minimum level of safety equivalence between vessel design, technology, and systems before, during, and after they change.

6.1 Safety hurdles throughout decarbonization

Various safety-related challenges accompany developments in decarbonization. These hurdles need proper management to minimize the risk of adverse events that could put an end to the positive developments in carbon-neutral shipping. For example, the properties of new and alternative fuels pose specific safety challenges compared with conventional fuels. The picture is complicated because – as DNV GL's Maritime Forecast to 2050 explains – alternative fuels have reached different levels of technical and regulatory maturity.

While using alternative carbon-neutral fuels[23], technologies[24], and operations[25] is key to achieving IMO decarbonization goals, operations with alternative fuels pose general and fuel-specific safety-related challenges that need understanding and managing. Figure 6-1 presents an overview of the status of regulatory and technical maturity of a selection of alternative fuels, highlighting safety as one key challenge. It shows how batteries, liquefied natural gas (LNG) as fuel, and hydrotreated vegetable oil (HVO) have come furthest toward meeting safety-related challenges, whereas hydrogen and ammonia have fewest rules and guidelines in place to control safety risks.

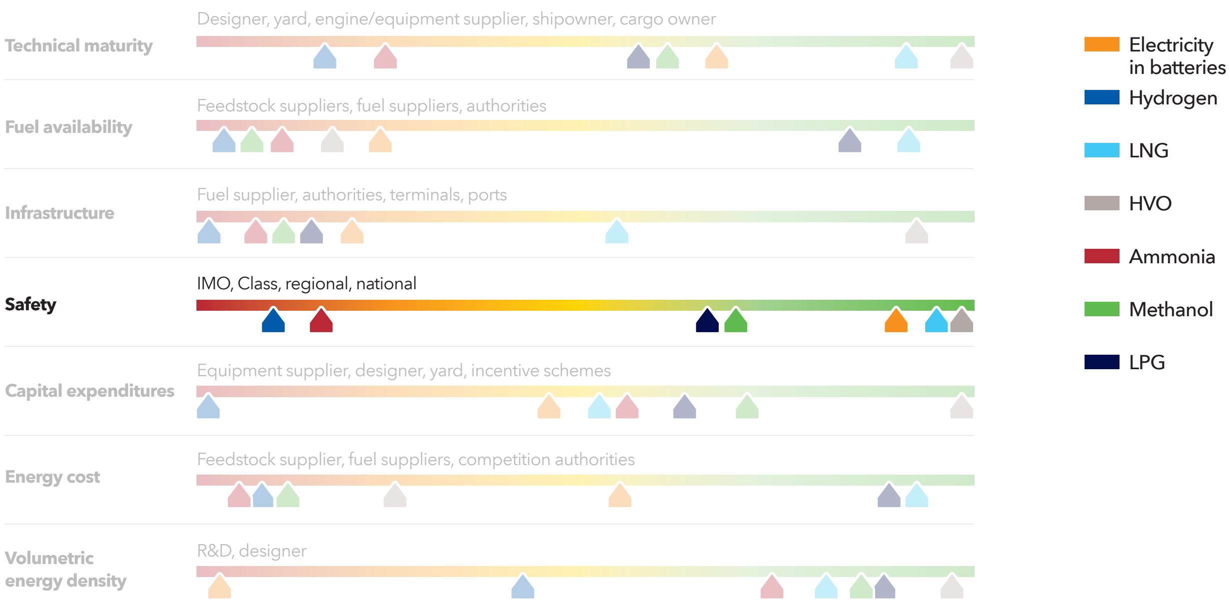
Flammable and toxic gas releases are among common safety-related risks associated with several alternative fuels. For example, toxicity is the main issue for ammonia, but flammability and lowered temperatures also need to be taken into account. For hydrogen, challenges relate to extreme low temperatures (-253°C) if stored as a liquefied gas, and high pressure (250–700 bar) if stored as compressed gas. Also, the hydrogen molecule is the smallest of all molecules, making it more challenging to contain; it also has a wide flammability range and ignites easily. The properties of ammonia and hydrogen may therefore lead to an increased overall risk level associated with their use as fuel on ships unless satisfactory safety systems and operations are implemented.

One safety-related advantage of using more digitalized systems in the transition to decarbonization is that such systems can reduce the need for manual operations and unnecessary exposure to dangerous situations. Fuel cells, for example, require less maintenance than combustion engines, reducing the need for follow-up by crew on board. Using fuel cells, and greater use of sensor technology, reduces the number of people being exposed to toxic fuels on board. Nevertheless, using alternative fuels safely still requires thorough consideration of how human performance may be influenced by new arrangements of equipment, new ways of collaboration, and new procedures and processes for bunkering.

While acute risks to safety are already a challenge to manage, the more implicit (latent) safety risks associated with the development and uptake of innovative decarbonization technology add another layer of complexity to the risk picture. In what follows, we elaborate on some of the safety hurdles that need to be managed to maintain robust and resilient systems capable of continuous improvement on the pathway to decarbonization.

23) e.g. ammonia, methanol, biofuels, liquefied natural gas, hydrogen, batteries.
24) e.g. energy harvesting through sails, kites, solar and wave power.
25) e.g. through slow steaming and energy-efficiency measures..

The Alternative Fuel Barrier Dashboard – indicative status of key challenges for selected alternative fuels in 2020



Key: Liquefied natural gas (LNG); hydrotreated vegetable oil (HVO); liquefied petroleum gas (LPG).

Figure 6-1: The Alternative Fuel Barrier Dashboard, reproduced from DNV GL's Maritime Forecast to 2050 (2020 edition). Safety is one of the key challenges.

6.1.1 Take a holistic view of risk for safe decarbonization

Most systems and technologies today rely on increasingly integrated automation and control systems. Systems that were traditionally separated and operated independently from others are becoming more interconnected. This creates an overarching risk that needs addressing for innovative vessel designs and new technologies.

Risks during regular and non-routine operations
Because risks associated with new technology are not necessarily accounted for by existing rules, it is not sufficient to blindly apply existing rules to new technology. This can become an even greater challenge when suppliers focus too much on the sub-system that they are responsible for, without keeping an eye on the system as a whole. This is the case when prescriptive rules for a sub-system are applied rather than following an alternative design process for a novel ship design. When fuel is only related to what drives an engine, for example, then the risks associated with how the fuel may influence engine operations for the vessel as a whole are insufficiently accounted for.

Another example of the importance of a holistic understanding of risk is related to slow steaming as a way to save fuel or comply with IMO's Energy Efficiency Existing Ship Index (EEXI). For slow steaming to be a sustainable measure, operators need to consider that it requires additional maintenance routines and inspections to ensure minimal engine damage. If this holistic risk is not addressed, then there is a chance that an engine can become damaged and threaten the safety of the entire operation.

A holistic understanding of risk is as important during non-routine operations, such as maintenance, as during regular operations. Those playing a part in the ability to perform correct and timely maintenance include crew performing regular maintenance on board; suppliers visiting vessels to perform maintenance; and people responsible for designing the technology and associated procedures for easy access and effective maintenance. It is necessary to understand how the activities and responsibilities of each of these stakeholders affect the safety and efficiency of the entire vessel and its operations. A practical example is related to Safe Return to Port (SRtP)[26], which requires a holistic understanding of how equipment that is out of operation for maintenance affects the operability and compliance of the vessel. DNV GL's SRtP notation[27] gives guidance on system design for vessels to meet their objectives.

Break down the silos
Technical barriers and system design are essential risk controls. However, technical barriers alone will not be sufficient to ensure equivalent or higher levels of safety if human and organizational (i.e. non-technical) risk controls are not accounted for in the holistic risk picture. Non-technical controls – e.g. risk competence, safety culture, and regulatory measures – are as relevant to the design of equipment and materials for handling alternative fuels as they are for designing infrastructure that will facilitate the safe widespread production, distribution, and bunkering of alternative fuels. In other words, although transformations in decarbonization require state-of-the-art technology, their sustained success depends on how, and in what context, this technology is applied. A robust approach to safety therefore requires a 'systemic perspective' focusing on the complex interaction between human, organizational, and technical factors that influence carbon-neutral operations (see also 5.1.1).

By adopting a holistic understanding of risk that spans human, organizational, and technical factors, all stakeholders including policymakers will be better able to identify gaps in their own knowledge and experience. This awareness would incentivize collaboration with other stakeholders to share knowledge and experience and connect all areas of responsibility in a vessel life cycle to break down the silos.

Barrier management provides the processes and tools that help to create the holistic risk picture by making the risks explicit, identifying what risk controls should be in place, and by monitoring the integrity of each of the safety barriers in a structured, systematic, and traceable way[28] (see also 5.1.1).

DNV GL's JIP on human-centred design of alert management systems on the bridge is one example of such a collaboration and how it raised participants' holistic understanding of risk.[29] The 12 organizations participating in the JIP represented the supply chain and shared common challenges in the design and implementation of human-centred alert management systems (see also 5.1.2). The consortium concluded that there was a need to appoint a system integrator as 'a spider in the web', responsible for integrating, optimizing, and communicating between stakeholders throughout the design process.

Taken together, there is an increasing need for system integration in the maritime industry as a way to break down silos and ensure that a common safety philosophy is implemented. A system integrator can be a valuable contribution to ensuring safe operations throughout the transition to carbon-neutral shipping. A system integrator can be appointed as the responsible party for establishing and maintaining a holistic risk picture throughout the design, development, implementation, and maintenance of new, complex systems. Such a system integrator could facilitate the process and keep a bird's-eye view on risk management while the suppliers and other stakeholders can focus on the risks and learnings that are associated with their specific areas of expertise. This lays the foundation for a holistic understanding of risk to support system robustness.

26) https://www.dnvgl.com/expert-story/maritime-impact/Notations-build-trust.html
27) https://rules.dnvgl.com/docs/pdf/DNVGL/CG/2019-07/DNVGL-CG-0004.pdf
28) https://www.dnvgl.no/news/dnv-gl-offers-a-step-change-barrier-management-solution-through-synergi-life-qhse-software-48787
29) DNV GL, 2016. Human-centred design of alert management systems on the bridge. Report 2016-1147, Rev. 1.

6.1.2 System resilience needs regulations based on collaboration and continuous feedback

Transformations aimed at decarbonization are creating an era of constantly changing requirements targeted towards rapid advancement of new technology to reduce vessel GHG emissions. The industry is navigating its way through this period of uncertainty and change as it moves toward an era of more established requirements based on an increasingly stable body of knowledge and experience.

Regulatory bodies and classification societies represent much of this knowledge and experience, which is essential for the robustness of maritime systems. Yet they also bear the responsibility of supporting the resilience of maritime systems by driving developments in decarbonization technologies and safe operations. The challenge, then, is for them to strike a balance between meeting industry expectations to proactively define rules and regulations while assuring the quality of new regulations.

Manage risk for new fuels and abatement technology
New fuels and abatement technologies pose new safety-related challenges and require additional risk controls to ensure acceptable levels of safety. As presented in Figure 6-1, ammonia engines and fuel systems are presently relatively immature compared with LNG and battery systems, and significant technical and safety challenges still need to be solved for ammonia alone. Also, little experience and few existing rules are available to cover the use of hydrogen as fuel. At the same time, hybrid solutions or those that can run on two or more fuels are under development. These parallel developments increase the complexity of design and operations and make it even more difficult for stakeholders to understand the risks and to perform operations at equivalent (or better) levels of safety.

While success criteria for more established alternative fuels can to a certain extent be transferred to other fuel types, there is a tendency to assume that risk management associated with one fuel type is fully transferrable to another fuel type. For example, although the success of LNG can lead the way for other fuel types, this does not mean that LNG-specific risk management will cover all the risks associated with hydrogen as fuel. There are still many risks associated with LNG specifically; and, in general, risks differ across fuel types and operations. The industry should not let down its guard and become risk complacent. Risk assessments for alternative fuels can be inspired by experience, but risk assessments should be conducted for all fuel types to ensure that the entire risk picture for any fuel type is covered.

Towards safe use of hydrogen as a maritime fuel

DNV GL leads projects that manage the risks associated with specific fuels. MarHySafe is one example, where we work together with industry stakeholders in a joint development project (JDP) to develop a common understanding of hydrogen safety and provide a basis for outlining a roadmap to hydrogen safety for the maritime industry.[30] Although regulatory frameworks should take care to cover the need for specific risk analyses for alternative designs, and should support the systems' resilience, the required risk-based approval process (i.e. the alternative design process where an equivalent level of safety needs to be demonstrated) is time-consuming and demanding. A project like MarHySafe is an important first step to remove hurdles to establishing rules and regulations for safe use of hydrogen as a maritime fuel.

30) https://www.energy.gov/sites/prod/files/2019/10/f68/fcto-h2-at-ports-workshop-2019-vii3-teo.pdf

Assess risk to bridge regulator gap for alternative fuels
Classification rules and international regulations are key to getting the technical barriers in place. However, there is typically a delay between the introduction of new alternative fuels and the implementation of new international rules and regulations. In the case of LNG as fuel, the first such vessel was built in 2000 to DNV GL standards while it took until 2017 for the IGF code[31] to come into force.[32] This underlines the crucial role of class, offering risk assessments as early as possible in the design process – e.g. hazard identification studies (HAZIDs), hazard and operability studies (HAZOPs) and Technical Qualification (TQ) – to close the gap between existing requirements and current practice, and to facilitate the resilience of new and alternative technologies.

Setting safety standards for future operations

DNV GL has taken a leading role in assessing safety risks and developing rules to drive the development and uptake of alternative fuels beyond those covered by the current IGF Code. Our classification rules[33] for the use of LNG, fuel cells, methanol, ethanol, and LPG are crucial steps towards ensuring safe design to protect vessels against fire and the release of toxic gases through segregation, double barriers, leakage detection, and automatic isolation of leakages. DNV GL also took the lead in generating knowledge about risks related to batteries through the Battery Safety JDP.[34] We are currently developing rules for safe operation of ships running on ammonia and hydrogen while working with industry partners to remove hurdles against the uptake of such fuels – for example, MarHySafe, and Green Shipping Programme.[35]

In the current absence of specific rules or deviations from existing rules, IMO Circular 1455 Alternative Design is often referenced. It describes the process for getting a design approved by applying a risk-based method. In applying the circular to large lifeboats, for example, the aim is to prove that the alternative design is as safe as the rule setting a maximum of 150 passengers per lifeboat. As such, this principle of safety equivalence becomes central to the safe application of alternative fuels and decarbonization measures. It assumes that policymakers are aligned on what safety level to aim for, and that they keep the holistic risk picture at the forefront so they can contribute to systems resilience.

6.1.3 Alternative fuels and changing operations require new skills and continuous learning

New alternative fuel types and modes of operation make vessels increasingly specialistic. This requires new and specific kinds of competence and experience. Many suppliers are engaged from other industries, but their lack of maritime-specific competence and experience can stand in the way of their understanding of the holistic risk picture, posing a threat to the safety of maritime operations.

If crew, suppliers, and other stakeholders are to gain a better understanding of the risks associated with emerging technologies, systems, and the distribution and operation of different types of alternative fuels, they should be offered competence development programmes and supervision that cover both general and fuel-specific risk management.[36] Competence development programmes should also focus on individual responsibility to be 'creatively worried', think outside the box, think the unthinkable, and remain mindful of new safety-related risks and opportunities for driving forward developments in decarbonization. The risk assessments that DNV GL performs and facilitates for industry stakeholders offer a starting point for discussion and subsequent learning to help raise each other's risk competence.

In order to maintain robust and resilient operations throughout this transformation, maritime owners, suppliers, and regulators all need to have in place a process for continuous improvement. Yet, for continuous improvement to happen, each stakeholder needs to be willing to learn through experience exchange and operational feedback. This means that the industry needs to advocate a learning culture that facilitates open and transparent communication.

Driving competence development and facilitating implementation of technical risk controls rely on a mature safety culture. An organization that fundamentally understands the importance of taking a systemic perspective of safety (See Section 5.1.1), of human-centred design, of investing in competence development, and of learning from events, is an organization that exemplifies a mature safety culture that will put safety first.

31) The mandatory International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) entered into force on 1 January 2017 along with new training requirements for seafarers working on such ships.
32) https://www.dnvgl.com/maritime/lng/ships.html#:~:text=In%202000%2C%20the%20first%20LNG,vessel%20projects%20with%20industry%20partners
33) https://rules.dnvgl.com/docs/pdf/DNVGL/RU-SHIP/2020-07/DNVGL-RU-SHIP-Pt6Ch2.pdf
34) https://www.dnvgl.com/news/new-dnv-gl-joint-industry-report-offers-recommendations-for-enhanced-battery-safety-on-vessels--164738
35) https://www.dnvgl.com/maritime/green-shipping-programme/index.html and https://grontskipsfartsprogram.no/wp-content/uploads/2021/01/Ammonia-as-a-Marine-Fuel-Safety-Handbook.pdf
36) For example, see DNV GL standard on Competence Related to the on board use of LNG as fuel. https://rules.dnvgl.com/docs/pdf/DNVGL/ST/2014-04/DNVGL-ST-0026.pdf

7 Conclusion

This paper presents a broad overview of safety hurdles that need tackling to safeguard maritime operations as the industry becomes more digitalized and decarbonized.

Digitalization increases system complexity and introduces new ways of operation and collaboration. We foresee that traditional risk management methods will be insufficient for the new complexity, and that centralized and dispersed teams will change how people work as organizations become a patchwork of multiple stakeholders. Decarbonization involves alternative fuels and operations with new safety-related risks. These include safety hurdles related to stakeholders working in silos with a focus on subsystems, a regulatory framework that cannot keep up with the pace of technological development, and suppliers and end users that lack maritime and fuel-specific competence.

Complex innovative technology is key to driving the transformations forward. Yet it is not enough for achieving and maintaining smarter and carbon-neutral shipping. Safety depends on holistic risk management to address the technical as well as human and organizational elements that contribute to safety, and account for the interaction between these elements. Digital transformation calls for system integration and new ways of managing risks associated with complex systems, while the transformation to carbon-neutral shipping requires that we collaborate to increase transparency, establish a strong regulatory framework, and create a culture of continuous learning.

Consequently, technological advancement should be complemented with efforts to keep people in the loop. This means that it should be possible for people to follow along with the technology so that they can monitor and understand what is happening at any given moment, in any given situation. This is not only about crew members, but also maintenance engineers, suppliers, designers, managers and regulators; people who can supplement the feedback from technical systems with their creativity, problem-solving abilities and operational insights provided that they have timely access to relevant information. As such, to reap the benefits of this era of transformations in digitalization and decarbonization, industry stakeholders need to collaborate from the beginning to the end of a ship's life cycle. The aim should be to create a shared focus on design and operations that support people's performance.

The industry has the responsibility and ability to safeguard maritime operations. Every maritime organization can, in their own way, play a part in facilitating safe and efficient performance, by balancing out function allocation between technology and people, considering human-centred design of systems, and ensuring the physical, mental, and social wellbeing of the people in future maritime systems. Ultimately, innovative technology, designed, maintained and operated by optimally performing people in organizations that embrace holistic risk management, is what will put the industry in the best position to transform itself through digitalization and decarbonization.

Digitalization – safety hurdles associated with greater system complexity

	Safety hurdle	Recommendation
1	Traditional risk-management methods will be insufficient	Focus on system performance rather than component reliability to manage increasingly complex ship systems
2	Centralized and dispersed teams will change how people work	Support people's roles/needs through human-centred design and a balanced function allocation
3	Organizations are becoming a patchwork of multiple stakeholders	Establish digital transformation strategies for how organizations should manage emerging risks

Decarbonization – safety hurdles associated with alternative fuels and modes of operation

	Safety hurdle	Recommendation
1	Stakeholders work in silos focused on subsystems	System integration to enable collaboration and transparency
2	Regulatory frameworks cannot match pace of technology development	Collective commitment to contribute with knowledge and experience to supplement missing regulations
3	Suppliers and end users lack maritime and fuel-specific competence	Develop lacking competences and a culture of continuous improvement

Table 7-1: Summary of main safety hurdles to overcome and recommendations to follow for safeguarding maritime operations during transformations.

ABOUT DNV GL

We are the independent expert in risk management and quality assurance. Driven by our purpose, to safeguard life, property and the environment, we empower our customers and their stakeholders with facts and reliable insights so that critical decisions can be made with confidence. As a trusted voice for many of the world's most successful organizations, we use our knowledge to advance safety and performance, set industry benchmarks, and inspire and invent solutions to tackle global transformations.

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