R&D ROADMAP FOR SMART & AUTONOMOUS SEA TRANSPORT SYSTEMS

October 2020

SINTEF TCOMS

Cover page: Autonomous vessels being developed and trialled in Norway and Singapore respectively. Top picture courtesy of Kongsberg, DNV-GL, SINTEF and NTNU. Bottom-picture courtesy of ST Engineering Electronics Ltd.

The Research Institutes' Roadmap towards Smart and Autonomous Maritime Transport Systems

A collaborative roadmap from the leading maritime research institutes in Norway and Singapore, identifying the most important research challenges as we journey towards smart and autonomous ships and ports.

The research institutes SINTEF Ocean and the Technology Centre for Offshore and Marine, Singapore (TCOMS) have developed a roadmap to prioritize and coordinate research activities towards the next generation maritime transport system with inputs from the Maritime and Port Authority of Singapore (MPA), Singapore Maritime Institute (SMI) and the Research Council of Norway (RCN).

"Smart and autonomous shipping has the potential to transform the entire maritime transport sector"

"To harness the full potential of connected and automated operations, we must include the needs of all stakeholders in the transformation of the transport systems.
If we succeed, Smart and Autonomous Maritime Transport Systems will be safer, more efficient and better for the global environment"

FOREWORD

Her Excellency Anita Nergaard, Norway's Ambassador to Singapore

Norway and Singapore are truly Ocean Partners. Our cooperation within the maritime and ocean space dates back almost 200 years, to when Singapore was an important port for the Norwegian merchant fleet, followed by the establishment of offices in Singapore by companies such as Det Norske Veritas (now DNV GL) and Wilhelmsen.

The Norwegian maritime community in Singapore counts nearly 200 companies within shipping and ships services, financial and legal services, and shipbuilding and related activities. The substantial Norwegian maritime and offshore engineering and equipment services cluster has a strong standing in Singapore, engaging in speciality vessels and rigs for Arctic conditions.

Singapore and Norway have both benefitted from cooperation on maritime research and technology development over the last 20 years. This agreement between TCOMS and SINTEF Ocean represents a new stage - it brings the cooperation into the future.

Singapore and Norway will continue to work closely together as the maritime industry tackles the challenges posed by technological disruptions, climate change and the demands for new skills.

We will remain Ocean Partners.

Mr Wong Weng Sun, Chairman, Singapore Maritime Institute

Singapore is a small country highly dependent on international trade and regards the maritime sector as a critical pillar supporting our economic development. As smart ships become more prevalent, it is essential for global ports such as Singapore's to prepare for the future of autonomous shipping. Smart ships will also help global trade and supply chains become more resilient by helping to protect the health and well-being those who live and work in the maritime sector through the use of remote control and automation.

In the past few years, Singapore has taken the lead to experiment with remote/autonomous technologies. Singapore has much to offer to the global vision of realising autonomous shipping, given the rich eco-system of public and industry R&D players in Singapore, and the MPA Living Lab which offers a uniquely challenging environment for players to testbed and validate their solutions.

I am glad that TCOMS and SINTEF Ocean, as national research institutes dedicated to maritime and ocean sectors in Singapore and Norway respectively, have come together on their own initiative to chart out the most important research challenges for smart and autonomous ships and ports. This collaboration is also reflective of the close maritime ties that Singapore and Norway have.

I look forward to seeing this Roadmap becoming a catalyst that rallies the global research community, including public institutions and industry, together to achieve the shared global vision for future autonomous shipping.

Dr Vegar Johansen, President, SINTEF Ocean

Smart and autonomous shipping is one of the strategic areas of SINTEF Ocean, and SINTEF Ocean has played a leading role in development of smart and autonomous maritime systems since the early beginning. The Norwegian Research Council has awarded the Norwegian University of Science and Technology (NTNU) and SINTEF Ocean two consecutive sentries of research-based innovation *Smart Maritime* and *Autoship*, and we are central in major EU research initiatives *AEGIS* and *AUTOSHIP*.

International collaboration is essential to further develop, and to successfully implement, smart and autonomous systems, and we are pleased to establish a committed collaboration with TCOMS in Singapore in this area. In the common commitment to pursue the sustainability goals for international sea transport, international collaboration between big shipping nations like Singapore and Norway plays a pivotal role.

We are very happy to have co-developed this comprehensive R&D Road-map, and trust that this will form a platform to direct future research and innovation in this important area.

Prof. Chan Eng Soon, CEO, Technology Centre for Offshore and Marine, Singapore

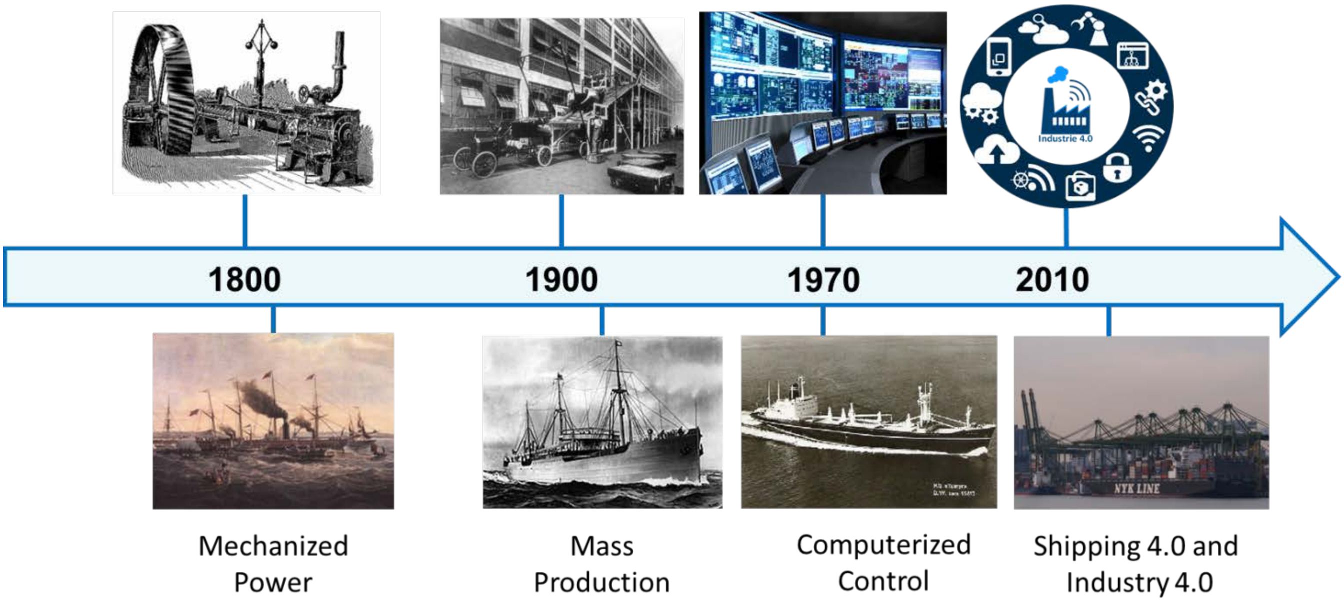
With the support of the Maritime and Port Authority of Singapore and the Singapore Maritime Institute, TCOMS set up a Centre of Excellence for Autonomous & Remotely Operated Vessels (CEAOPS) in November 2019 to drive R&D in Maritime Autonomous Surface Ships (MASS). CEAOPS focuses on research and technology innovation required for the safe and efficient operations of smart vessels, especially in challenging operating environments.

When we decided to formalise our collaboration with SINTEF Ocean through a Memorandum of Understanding in 2019, both organisations readily agreed that MASS would be our first collaboration area. As maritime nations, Singapore and Norway have been pursuing MASS R&D on various fronts. We recognise that we can do more to help advance the global MASS evolution through strategic collaboration, starting with this R&D Road-Map that identifies key technology areas essential for Smart & Autonomous Maritime Transport Systems.

We hope that this R&D Road-map can help spur deeper conversations amongst our fellow public research organisations and industry partners on the future of MASS and smart maritime operations. Through open innovation, the industry will be able to accelerate the realisation of new concepts in maritime operations.

AUTONOMOUS AND SMART TRANSPORT SYSTEMS

Shipping has followed the industrial revolutions closely, ever since the invention of the steam engine around 1800, through mass production and diesel engines in 1900, to the introduction of computer control in the 1970s.



We are now seeing the impact of Industry 4.0 in the shipping sector: Smarter ships and ports, digital data exchanges, automated processes, autonomous ships and advanced robotics. Also, new work processes and business models are finding their place in the maritime transport systems. Singapore and Norway, as leading maritime nations, are in the forefront of developing and adopting the new technology and need to keep a continuous and high focus on our research and development activities to stay ahead.

In June 2019, SINTEF Ocean and TCOMS signed an MoU to co-develop future maritime and offshore systems and solutions. Smart maritime technologies and autonomous vessels were identified as first priorities.

To chart a course for international and collaborative research and development, topics of particular importance have been identified through a series of workshop discussions together with MPA, SMI and RCN. Main focus has been on technology, since this is at the core of our capabilities. Our ambition has been to create a roadmap that will align international research and innovation (R&I), and inspire international research collaboration within the area of smart and autonomous shipping.

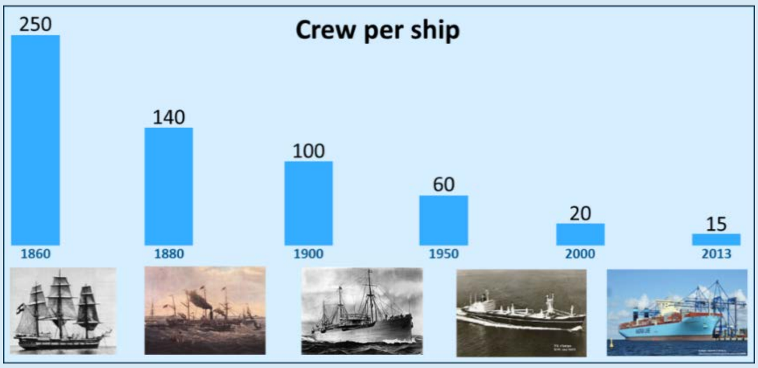
Smart or autonomous ships?

The smart ship is the result of a continuous increase of automation in ship processes, in decision support systems for the crew and in better coordination through more advance communication systems between ship and port. The remotely controlled engine room and the anti-collision radar are important early milestones in this development journey. Since 1990, it also includes automated and digital information exchanges.

The autonomous ship is a smart ship that has sufficient automation on board to operate without crew intervention for extended periods. Autonomous navigation, with complex decision-making capabilities, can serve as example in this respect. In the future, the crew may be located on shore, monitoring and guiding the ship in complex situations.

Fully autonomous vessels can be re-designed without the traditional superstructure, hospitality facilities to accommodate the crew and crew safety related equipment that would enable more efficient layouts and cargo operations. Traditional design consideration around economy of size will be less important. New and more flexible transport systems can evolve using more and smaller ships, supporting a new service-driven eco-system for cargo transport.

Smart ships provide the platform for a myriad of technologies to integrate and make our current transport systems more intelligent. Autonomous ships give us the possibility to re-imagine and re-invent our transport systems. Both are necessary steps towards a future sustainable world transport system.



Pathway towards smart ships: More efficient and integrated operations lead to a dramatic decrease in crew size.

The developments will continue towards the fully cooperative, connected and automated maritime transport system.

Mission Statement

The Research and Innovation (R&I) collaboration of SINTEF Ocean and TCOMS is driven by the mission to:

- Accelerate the global maritime transformation
  towards smart and autonomous ship solutions;
- Provide a leading platform for international collaboration in maritime research
  to advance the state-of-the-art;
- Create opportunities for open innovation and
  the next generation maritime business; and
- Contribute to the development of new legislations, laws and enforcement
  to enable a sustainable autonomous maritime industry.

This requires wide international co-operation and we invite other institutions to join this effort.

Aim of this Document

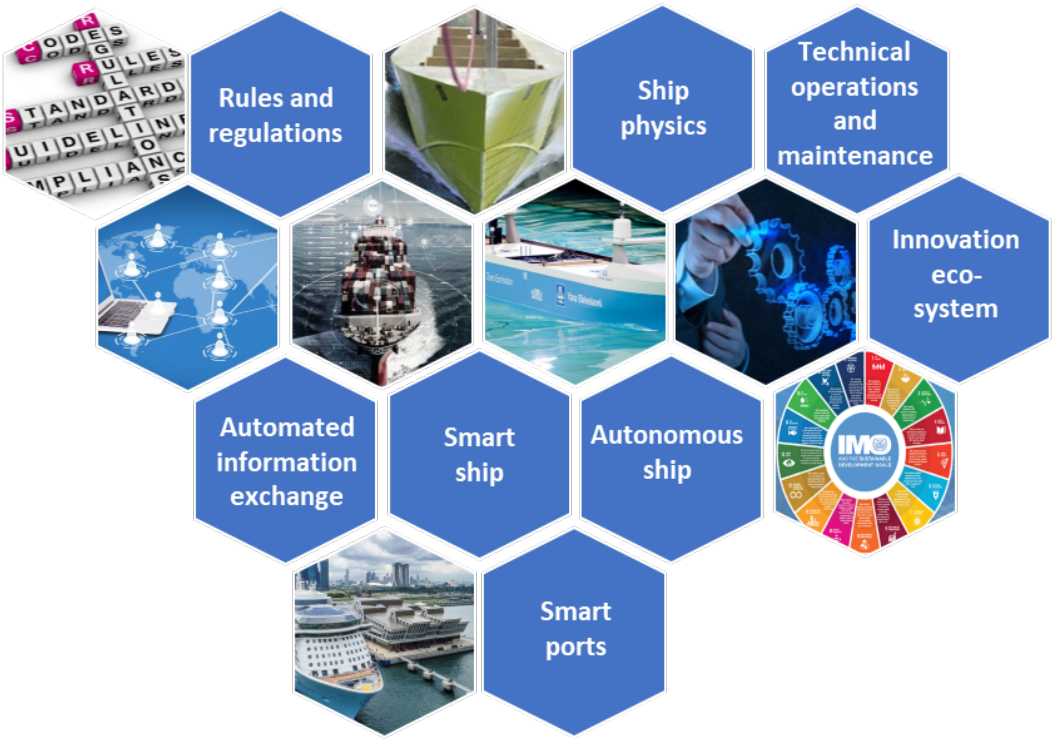
This roadmap presents the critical areas and elements that were considered as key capabilities to enable the development of smart and autonomous transport systems. It is through the proper integration of these elements within and across domains, that we will be able to harness the synergies and ensure the successful development of our collaborative projects.

The roadmap also helps to communicate the need for commitment from the various stakeholders in the international maritime industry to work together towards a transformative change that will benefit the maritime sector and the world.

Critical Research Areas

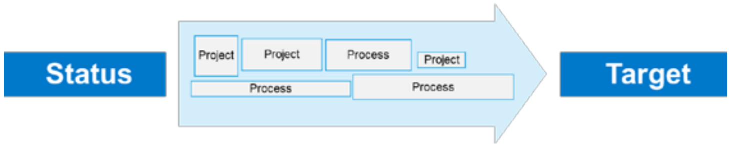
The main areas that will require research and innovation to help accelerate the establishment of smart and autonomous shipping are:

- Rules and regulations
- Automated information exchange
- Smart ships
- Autonomous ships
- Smart ports
- Ship physics
- Technical operations and maintenanc
- Innovation eco-system

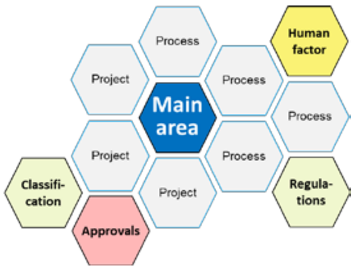


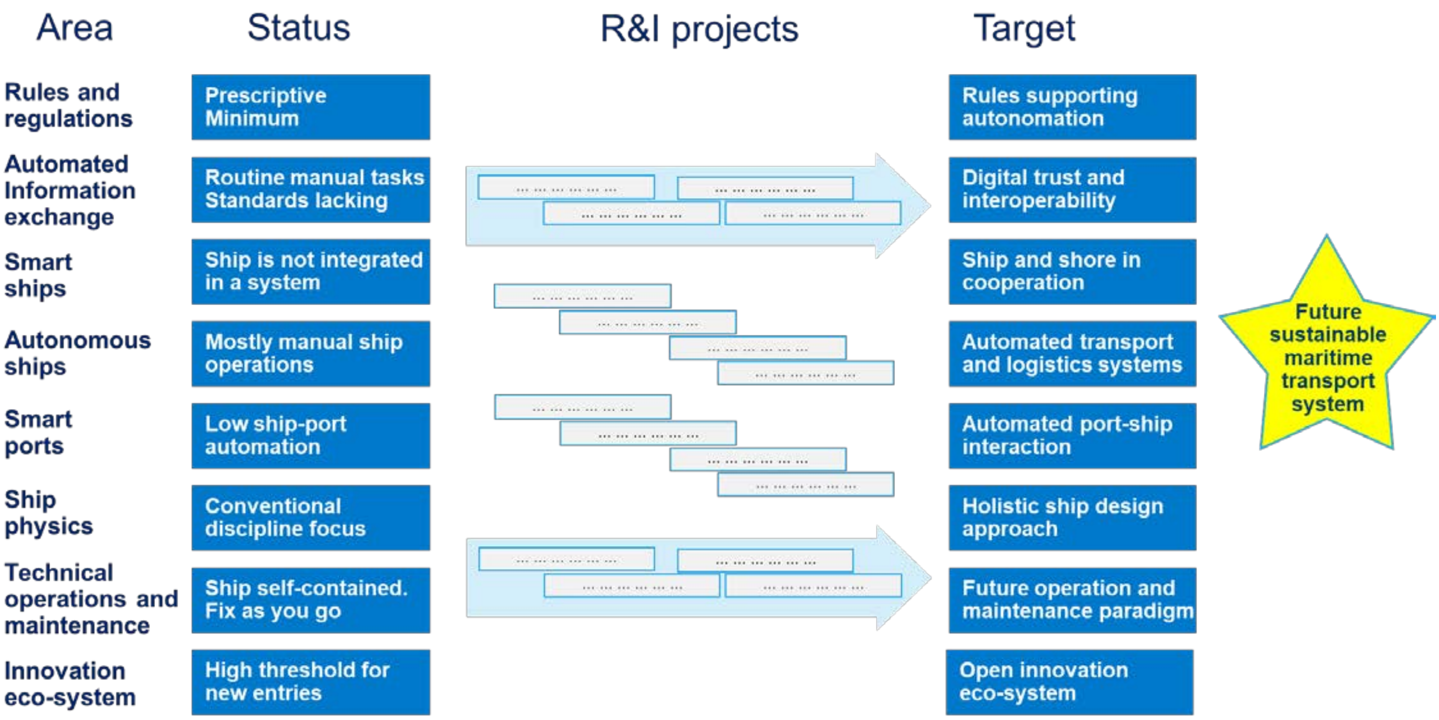
How to read the Roadmap

Within each main area, the roadmap identifies key elements to indicate how future operational systems would look like and to identifies future research, development and innovation needs. This is indicated as a development process from the present state of affairs to some envisaged future state.



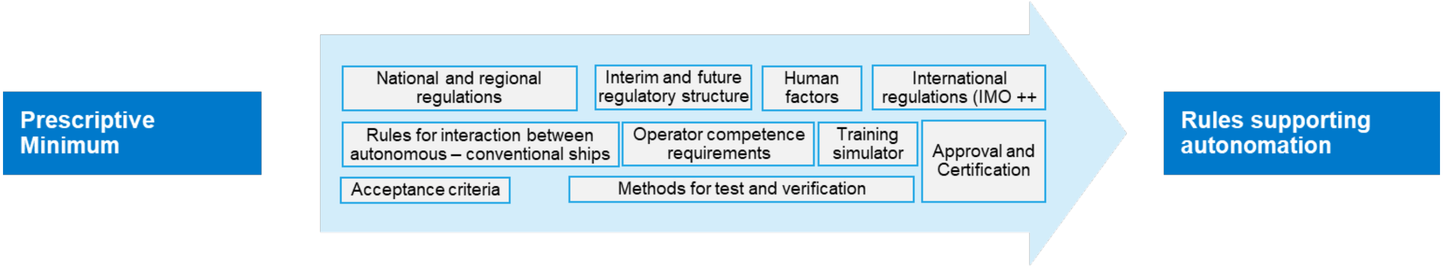
Relation diagrams indicate innovation projects / processes that are related in kind. Colour codes indicate dependencies on strategic documents, rules and regulatory bodies (red), human factors (yellow) and identify areas of high priority (red).





The complete roadmap is shown in the last page.

RULES AND REGULATIONS



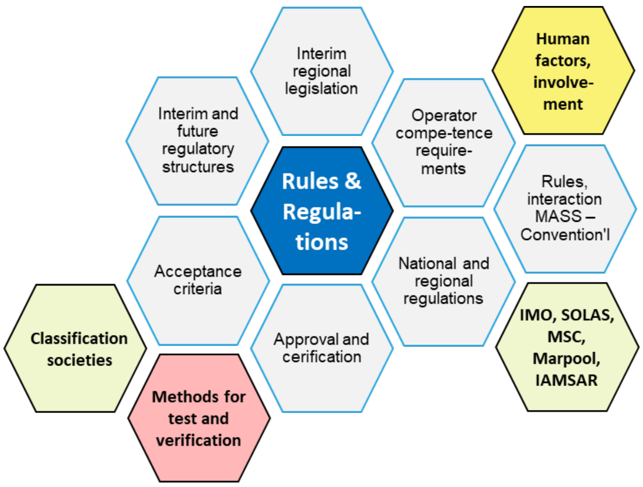
The regulatory environment plays a critical role in the transformation towards smart and autonomous maritime systems. Smart and autonomous maritime systems will depend on new operational concepts and technological capabilities that are already rapidly evolving. Corresponding rules and regulations will have to be developed in parallel to ensure safe deployment of these new technologies.

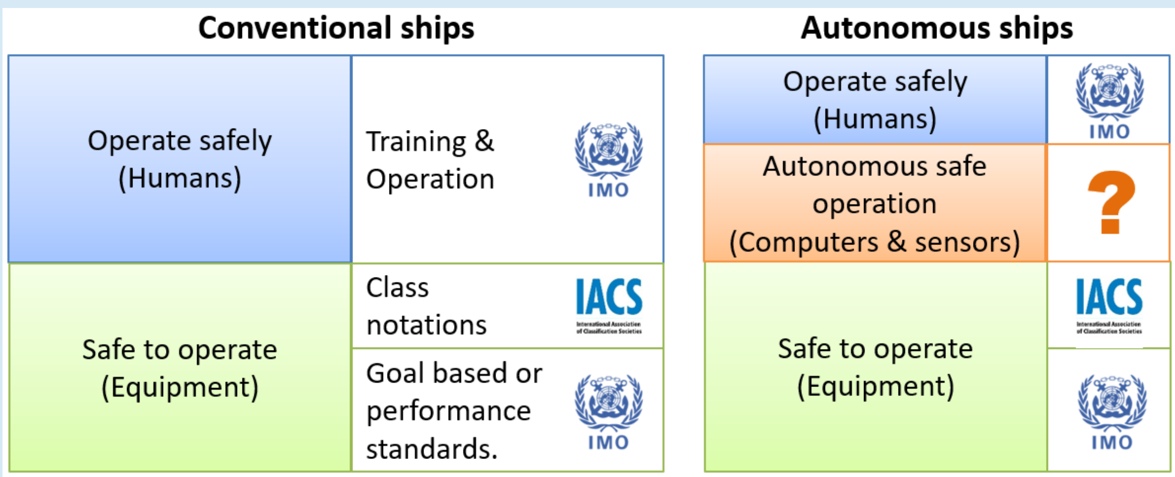
To enable timely development of rules and regulations, our international, regional and national authorities will need to know which technology and operations to target first, and to be provided with the tools and methods to efficiently enforce these rules and regulations.

In addition to the international efforts at the IMO, regional and national regulations should also be addressed – especially in view of the developmental trends where the autonomous systems will start to see operational use within the jurisdiction of one or a few partner countries. Publications that are effectively adopted by the maritime sector will be acting as de facto common standards. As such, Guidelines, Codes and

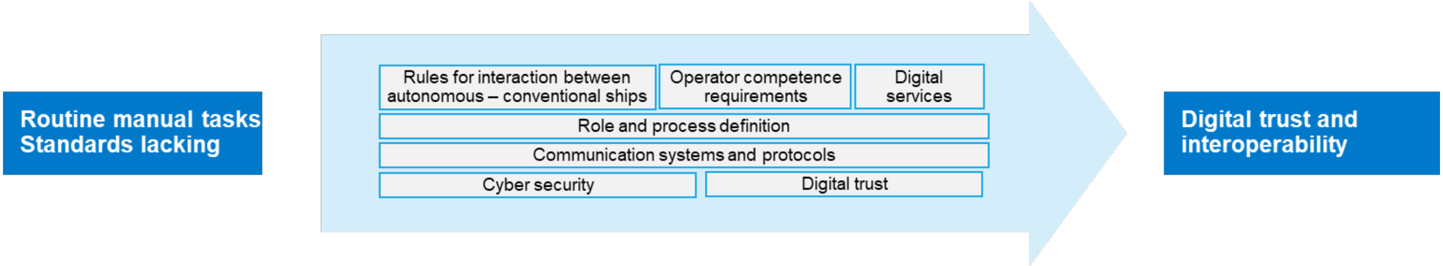
Recommended Practices and Standards should also be covered as part of this effort. As illustrated in the figure above, components of the maritime system such as conventional vessels, smart vessels (that have a high level of automation and digitalization on board), future MASS vessels, the regulatory bodies, and the ports and infrastructure that the vessel will operate in should all be taken into consideration, so as to provide a holistic picture of the overall complex maritime system.

As organisations with technical expertise on the *behaviour and response* of vessels, SINTEF Ocean and TCOMS would like to collaboratively develop approaches and methodologies for testing and verifying the performance of smart and autonomous maritime systems. This will help provide a harmonised basis for continued advancement of new vessel concepts as technological capabilities evolve.





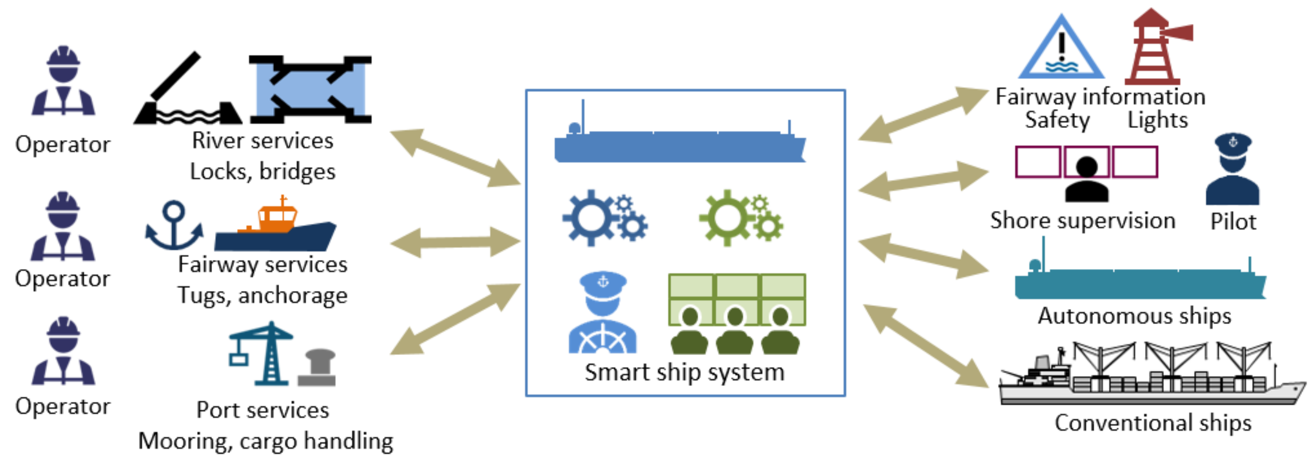
AUTOMATED INFORMATION EXCHANGE



At the heart of smart and autonomous ships lies the automation of work processes, both technical and administrative. The most critical are the cooperative processes that involve the ship and the entities it works with. This includes, e.g. automated port systems for berthing, mooring and possibly towage, reception of environmental and other information about its surroundings, and administrative reporting obligations to port and coastal states.

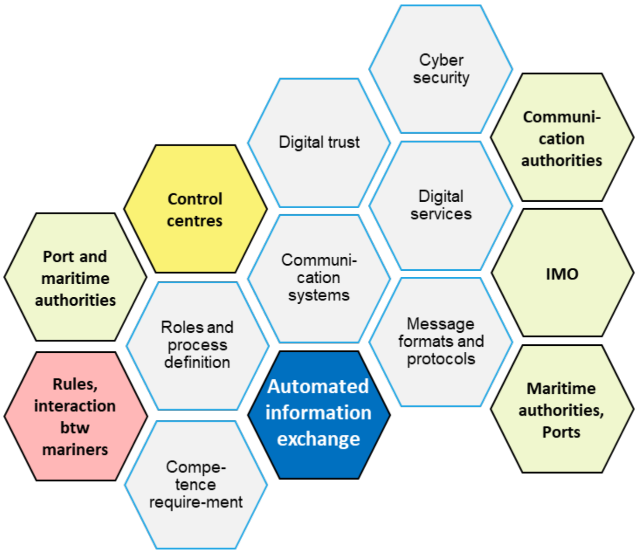
Automation of processes requires reliable communication facilities, digital data exchanges as well as a cyber-security framework to provide the trust that is necessary to remove humans from the processes. Process automation also requires a clear understanding of the respective cooperative roles and the expectations that each role should have to each other.

An area of particular importance is the interaction between autonomous and conventional vessels. MASS could be made to behave as close to a conventional ship as possible, but a safer and more efficient proposal is to improve the cooperation between these two types of vessels. For example, remote pilotage could be a requirement for MASS, but can also be useful for conventional ships as it would enhance or supplement the pilot decision making considerations.

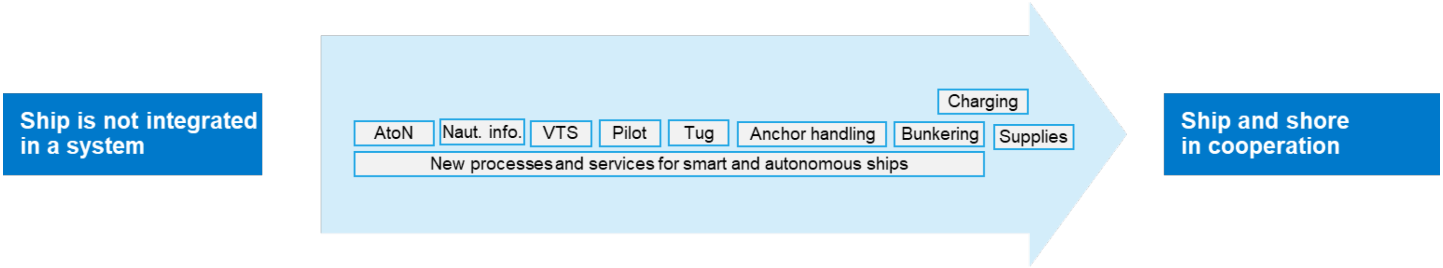


Specific fields of interest are illustrated in the figure below, where both information security, trust, digitalization, as a clear understanding or definition of roles and processes are important. Protocols for the following information exchanges will need to be addressed in this context:

- Ship-ship and Ship-land
- Off line simulation and analytics
- Improved ship communication
- Communication between automation system
- Security within communication



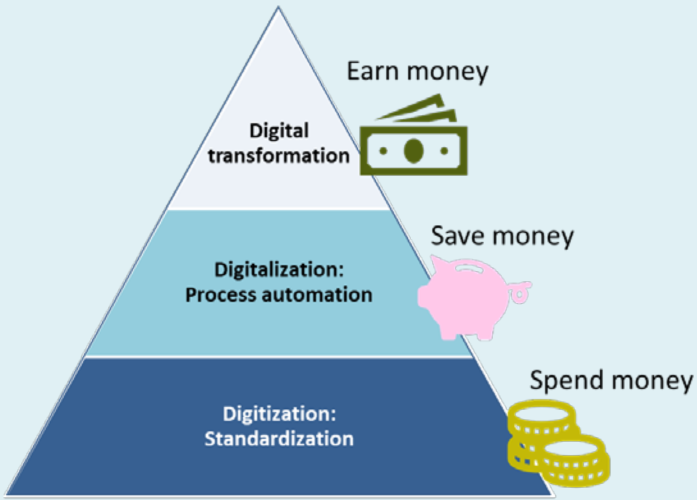
SMART SHIPS



There has been a steady adoption of smarter technologies in the maritime sector, from an initial wave of digitization, a subsequent digitalization and in the near future a digital transformation of the shipping industry. These advancements have formed a pathway for the continuous increase in maritime automation. As such, the development towards smart ships is more familiar to the existing maritime stakeholders. This is a necessary complement to the emergence of autonomous ships and revolutionary ship designs, where new market entrants may emerge.

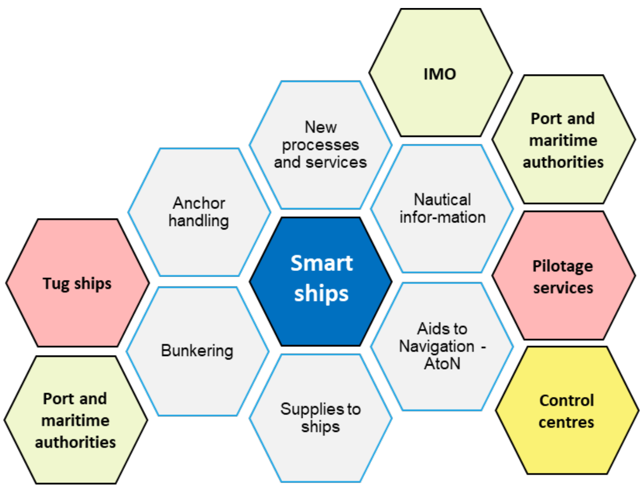
SINTEF Ocean have developed the Shipping 4.0 concept, where the objectives is to identify the maritime elements regards the industry 4.0. Following elements have been lifted as important, which is highly relevant for the Smart Ship development:

- Robotics and autonomy
- Cyber security
- Open system integration
- Internet of things at sea
- Cyber physical systems
- Data analytics
- Augmented reality
- Simulation and optimization
- Internet of services at sea

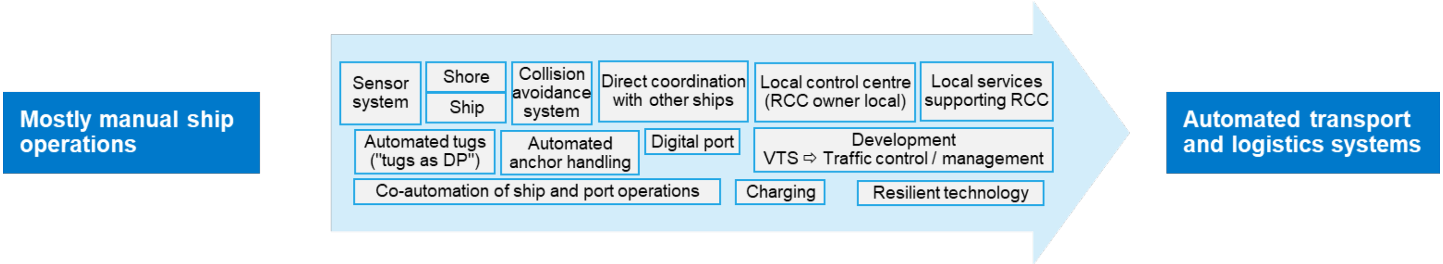


From our perspective, being the respective key maritime research organizations of Norway and Singapore, “Smart ships” should encompass a range of elements across the maritime transport system, in order to fully improve the operational efficiency and safety. As an example, a "Smart Ship" will not be able to function in an optimal manner in a conventional port that lacks the corresponding infrastructure systems to support the intelligent systems, which means the sensors and the different transport systems should be integrated. Operational efficiency and safety must be built across the transport systems.

Beyond the cargo vessel developments, enhancements to navigational infrastructure, systems for interfacing between vessels and ports, including traffic guidance systems and port-service vessels (e.g. tugs and pilotage services) should also be considered. The high priority boxes defined are the development of Tugs and innovative Pilotage services which would also include autonomous ships. For both services the ports and maritime authorities will be stakeholders that will have interest in the solutions, this includes the VTS, the Coastal Administration, the Pilot services, and the local authorities as a port.



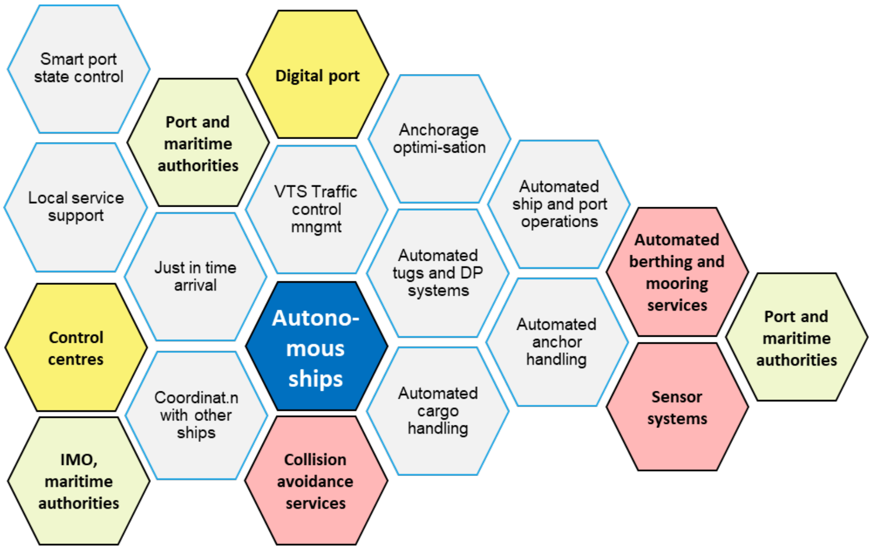
AUTONOMOUS SHIPS



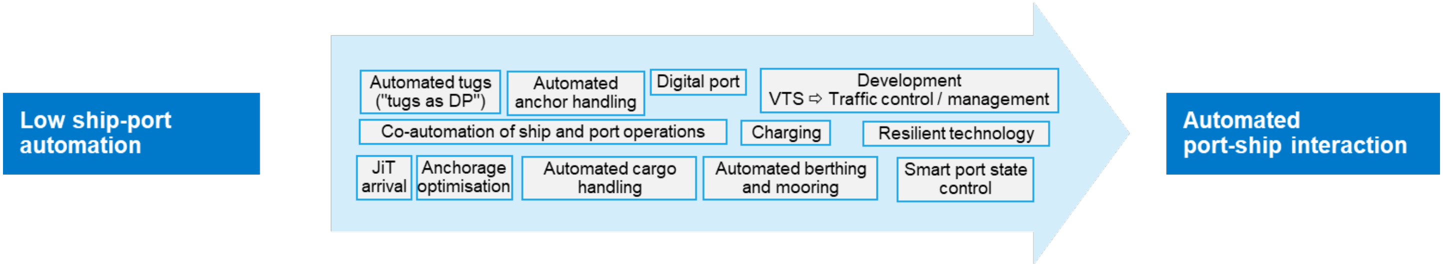
The transition from smart to autonomous ship is gradual and it can be argued that the most distinguishing factor for autonomous ships is that they can be designed without an onboard crew. This enables new ships design, new transport systems and possibly new business models. Thus, autonomous ships represent a potentially disruptive new technology. However, with ships being large and expensive assets, it is not likely that the autonomous ship is completely without humans in the loop. A Remote Control Centre (RCC) will be an important component of the autonomous ship system.

For a ship to operate without crew, we need to replace human sensing, object recognition and decision making with computers. With an RCC in place, this replacement need not be complete, as we have access to human support in particularly complex situations. Challenges here are obviously the complexity and reliability of the new sensor and automation systems, but also safe and efficient interaction between humans on shore or other ships and the automation systems. Autonomous ships will also rely on highly automated port processes to compensate for the lack of onboard persons to handle, e.g. towage, anchoring, berthing, mooring and cargo handling. This requires new types of cyber-physical systems in the port that can interact tightly with the visiting ships. This requires new standards for communication and interaction. We will also need new types of interactions between Vessel Traffic Services (VTS) and autonomous ships, including their RCC. This may include more prescriptive instructions from the VTS and a highly digitalized interface between the autonomous ship, the VTS and other aids to navigation.

Research and development on sensor and automation systems that can replace humans on the ship, but still efficiently interact with humans on shore or other ships, have been identified as pertinent topics in the development journey towards autonomous ships. Quantification of actual capabilities and testing against criteria that have been developed in the context of these topics are also relevant tasks. Testing should include numerical simulations as well as model testing and full-scale experiments. There is also a need for a more standardized approach to design, testing and communication to keep the cost of new autonomous ships on a reasonable level. Today's projects are one-off and generally too expensive for more wide-spread use of the technology.



SMART PORTS

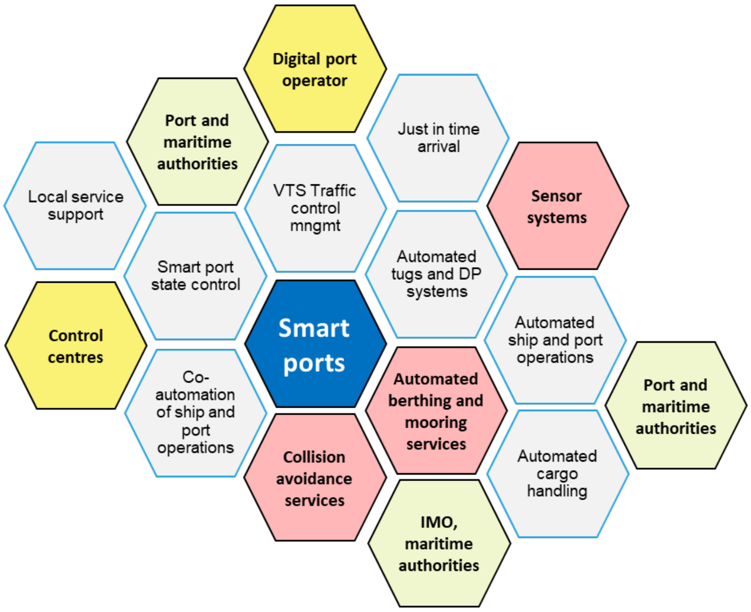


Ports are indispensable components of the maritime transport system, serving as the interface nodes between the sea and land. With the advancements of digital technologies, many ports have already deployed smart solutions to optimize operations and enhance productivity for today's ships. Developments to date include a significant evolution of shore-based systems and a growing pool of initiatives towards realising smart and autonomous vessels. SINTEF Ocean and TCOMS believe that it is timely to pursue a fully integrated ship-port approach towards this complex system-of-systems. This is necessary in order for ports to fully harness the benefits of smart and autonomous vessel developments.

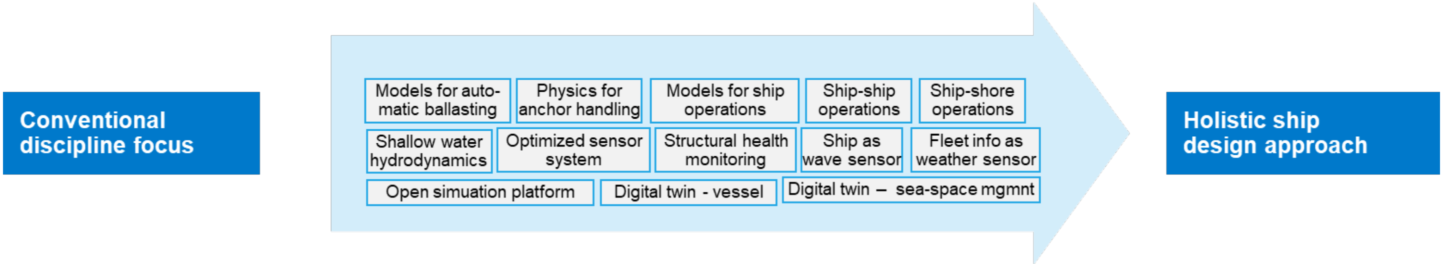
This requires a continuous improvement of automation and autonomy in ship-related operations in port (e.g. bunkering and re-supply services), to complement ongoing shore-side advancements in areas such as cargo handling. Similarly, smart capabilities will be required to enable the remote or autonomous operations of tugs including the mooring and berthing of cargo vessels.

Singapore Port, 2017

Extending the integration between the port and ships, as well as further improving transport efficiency (both in terms of monetary and spatial resources) will require the operationalization of Just-in-Time vessel arrivals and more intelligent coordination and management of vessel traffic from a fleet management perspective. Leveraging the increased connectivity and data availability, smarter approaches for verifying the compliance of foreign-flagged vessels to international conventions (i.e. Port State Control) can be implemented.



SHIP PHYSICS



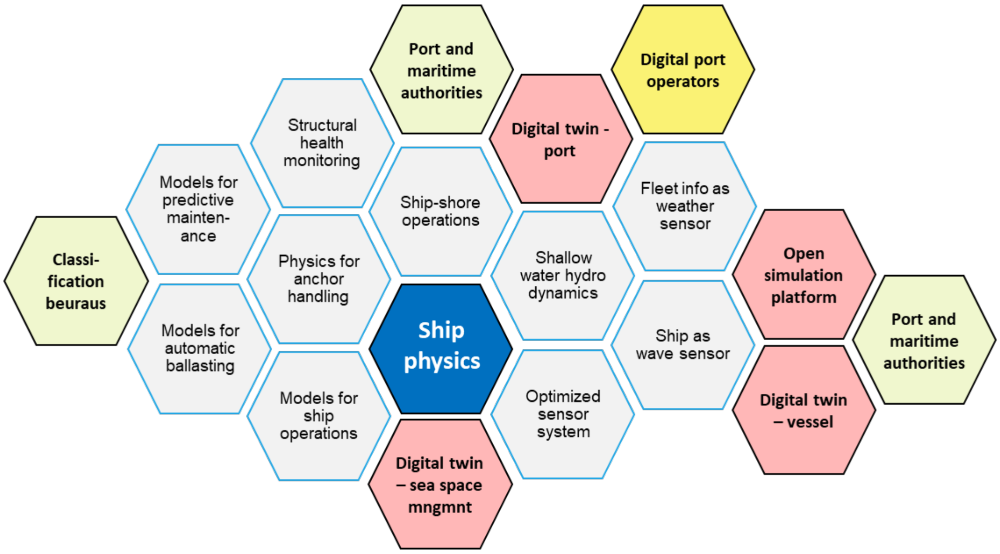
Ships physics is a key enabler for smart and autonomous maritime systems. On existing vessels, safe and efficient operations are enabled by sound conventional engineering and good seamanship, which in turn is based on the experiential knowledge of the human operators. With machines becoming more involved in the decision-making processes and in the actual operations of maritime systems, deeper and better understanding of how each system component behave and respond in real-world conditions is required.

It is envisioned that future operation models of maritime systems, including the vessel fleets and traffic management centres, will encompass various capabilities such as voyage optimization and predictive maintenance, as well as the coupling of shore-based centres within the decision-making and operational control processes. The development of such capabilities will require in-depth knowledge of the hydrodynamics and structural response characteristics as well as the harnessing of data enabled through developments in sensing technologies, to build digital twins of the physical systems that can be used to anticipate and provide a priori assessment of future scenarios.

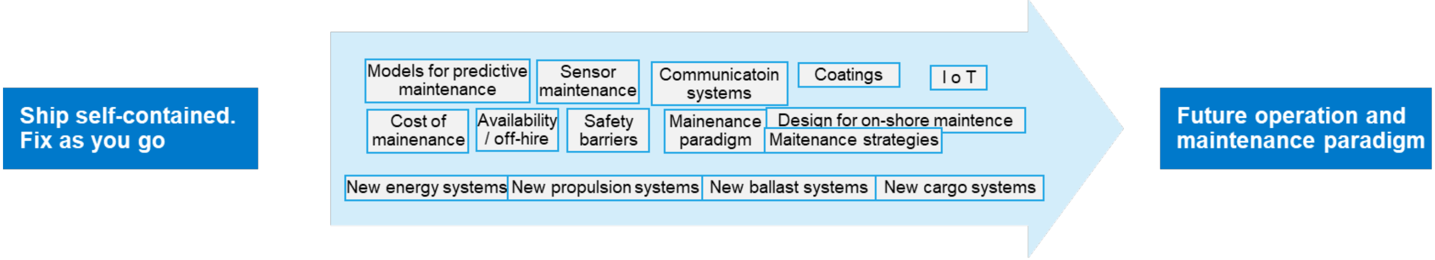
Left courtesy of Keppel SMIT and Keppel Offshore and Marine Ltd, Right: Courtesy of Kongsberg and Norsk Hydro.

As research facilities, SINTEF Ocean and TCOMS aspire to lead collaborative research efforts into the physics of how vessels interact with the surrounding environmental forces, as well as with other components of a given maritime system (e.g. vessels or shore management centres) that would enable the development towards autonomous maritime systems.

SINTEF Ocean and TCOMS have identified digital twinning, as well as the building of open simulation platforms, as key areas for research and development within the topic of ship physics. In this context, the system-level models required for the management of sea space are a continuum of vessel digital twins, moving from a vessel-centric perspective to a system-of-systems view of ship physics. This is essential when considering the interactions and responses between various vessels, as well as with the other components and the environment.



TECHNICAL OPERATIONS



Technical operations and maintenance are critical factors for an autonomous maritime system. Since people are not located on board the vessels during a voyage, the maintenance work must be done either periodically or when the vessel is berthed in a port. New ship designs will have to balance a replace vs. repair maintenance policy. Effective safety barriers and inherent safety through design will be even more important. New procedures for classification need to be established, e.g. relying more on sensor data and predictive maintenance embedded in ship systems.

Autonomous vessels need to incorporate a high level of self-awareness of technical status. Keywords for building awareness, and typical processes will be:

Detection Identify the vessel status based on data from sensors and vessel behaviour from monitoring

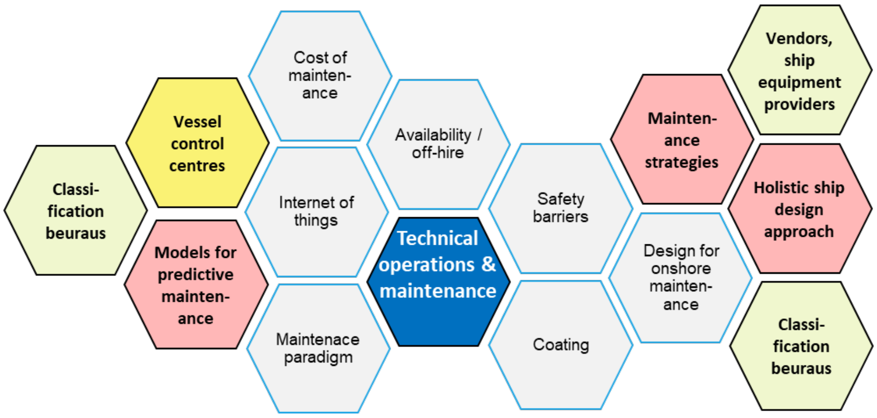
Analysis Do analyse the technical condition, calculate vessel capabilities, do risk and condition estimates, build barriers.

Action Plan and perform technical maintenance. Give control to local taskforces to do needed work to achieve acceptable technical condition, design the vessels for onshore maintenance. Contact classification when applicable.

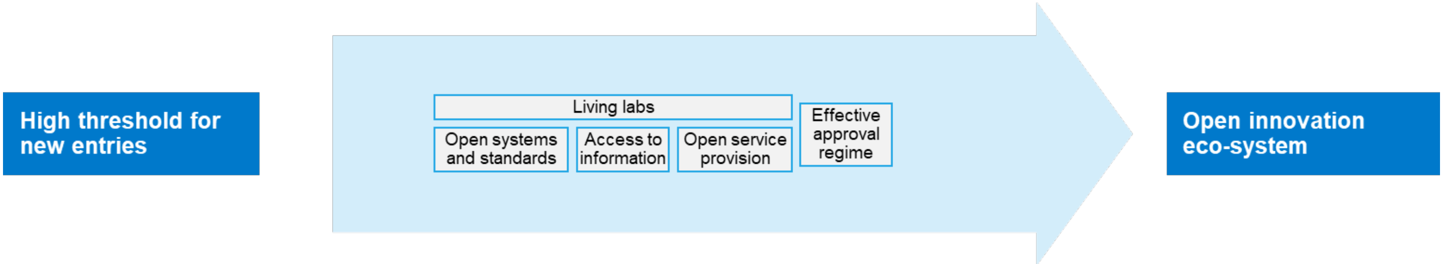
Control Re-establish the high technical status of the vessel and go back to normal operation after maintenance work has been performed.

In addition to Classification societies, vendors, and equipment providers, the main users of the technical operations will be the vessel control centres, that will perform the daily follow-up of a vessel and have first-hand information to the sensor data coming from the vessels. There will be a need for common practices - at an international level, where standardization and maintenance strategies will be an important contribution to the area. The regulators need to understand the vessel status to calculate the vessel condition, and assure that the vessel is within accepted technical condition.

As organisations with technical expertise on the *behaviour and response* of vessels, SINTEF Ocean and TCOMS would like to collaboratively develop approaches and methodologies for testing and verifying the performance of smart and autonomous maritime systems, as well as estimate the technical condition of a vessel. This will help provide a harmonized basis for continued advancement of new vessel concepts as technological capabilities evolves and new models for predictive maintenance are developed.



INNOVATION ECO-SYSTEM

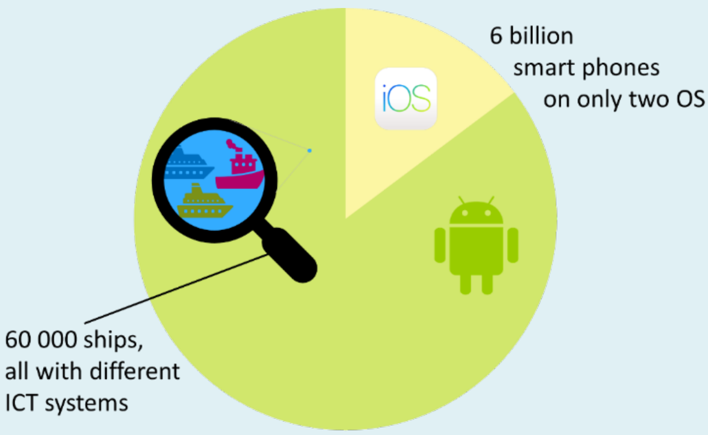


The maritime sector is small. There are only around 60,000 larger ships in regular international operations. Of these, an even smaller number can make efficient use of new and advanced technology and among these few ships, hardly any are identical in terms of ICT systems and infrastructure.

This means that many new products need costly engineering and customization for each new ship it is installed on. In addition, a complex regulatory framework creates additional costs and problems for existing and new companies alike.

A roadmap that aims at real changes in the maritime transport systems must also address these obstacles and provide a working ecosystem for the new products and services that are developed. We need to change the ecosystem so that more efforts can be channelled into product development and less on customization, regulatory red tape and complexity.

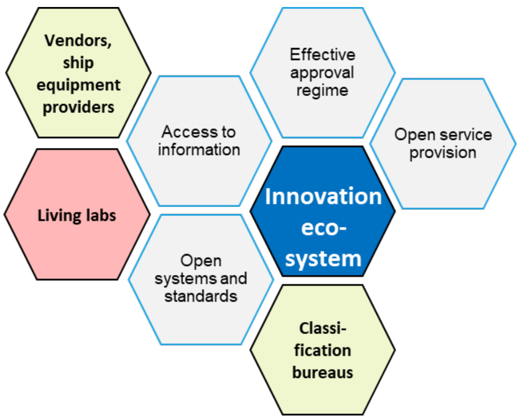
One obvious answer to the above problems is better and more efficient standards, for communication, information exchanges, increased automation as well as for regulatory compliance. These standards must be available for ships, ports and shore services, and the whole maritime transport industry.



Furthermore, the standards need to be international and open. The shipping sector is international by nature and we need markets for the new products that are not limited by geographical constraints. Also, for the acceptance of the specifications, they need to be neutral and precompetitive.

The working ecosystem would also ideally be supported by a regulatory environment that facilitates innovation through the availability of regulatory sandboxes and living labs. They allow for companies and public research institutes to carry out live trials of new ideas and technologies in actual environments supervised by the regulator and with appropriate safeguards. For example, the Maritime and Port Authority of Singapore MPA Living Lab consists of physical and digital spaces, that support the testing and validation of solutions and technologies. It also includes physical test-beds at sea to facilitate trials of marine drones, autonomous vessels and wireless communications technologies in the Singapore port environment. Similarly in Norway, the Norwegian Maritime Administration and the Norwegian Coastal Administration have designated new areas in the Trondheim fjord, in Ålesund and in the Oslo fjord by Horten as new test-beds for sailing with autonomous vessels.

To foster a vibrant innovation ecosystem, it would be essential to have a conducive business environment that encourages collaboration and the growth of start-ups. Technology accelerators with a focus on the maritime sector, such as Singapore's PIER71 (Port Innovation Ecosystem Reimagined @ BLOCK71), could catalyse collaboration between maritime companies and technology start-ups to address industry-wide challenges.



THE ROLE OF RESEARCH INSTITUTES

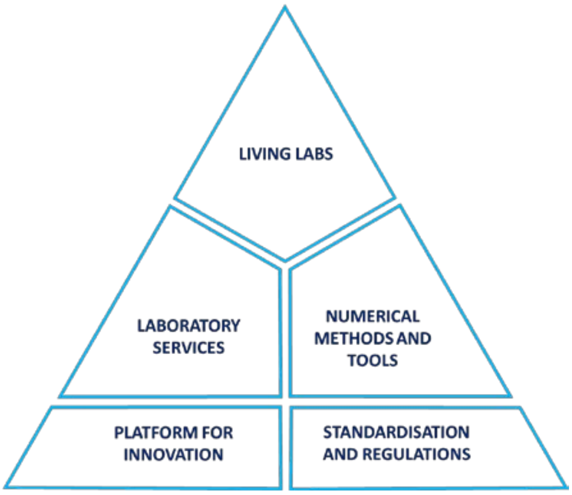
TCOMS and SINTEF Ocean are national competence centres with a clear responsibility for supporting our respective national industries to improve competitiveness and quality of products and services.

However, as the following roadmap shows, there are several areas where cooperation is to be preferred over competition, and it is also our national obligation to highlight these areas and establish the necessary international contacts to make this cooperation possible. Typical areas are basic enabling technologies, precompetitive concept studies, design or test standards and digital interface standards.

We also recognise that the development of autonomous ship requires international collaboration to provide enough resources to address all the challenges that deployment of such system faces. These are particularly related to design and operational principles, test criteria and test principles, interfaces to port systems and interfaces with other ships.

Finally, independent research institutes can support regulators, class societies, industry, operators and users alike, without prejudice to their respective interests. This is particularly important in the area of autonomous ships as these do not replace conventional ships, but need to be integrated in a completely new maritime transport system where the ship, port, port and fairway services as well as the logistics operations must be looked at as one system rather than individual and independent components.

- Research and development
- Laboratory services
- Numerical methods and tools
- Living labs
- Standardisation and regulations
- Platform for innovation



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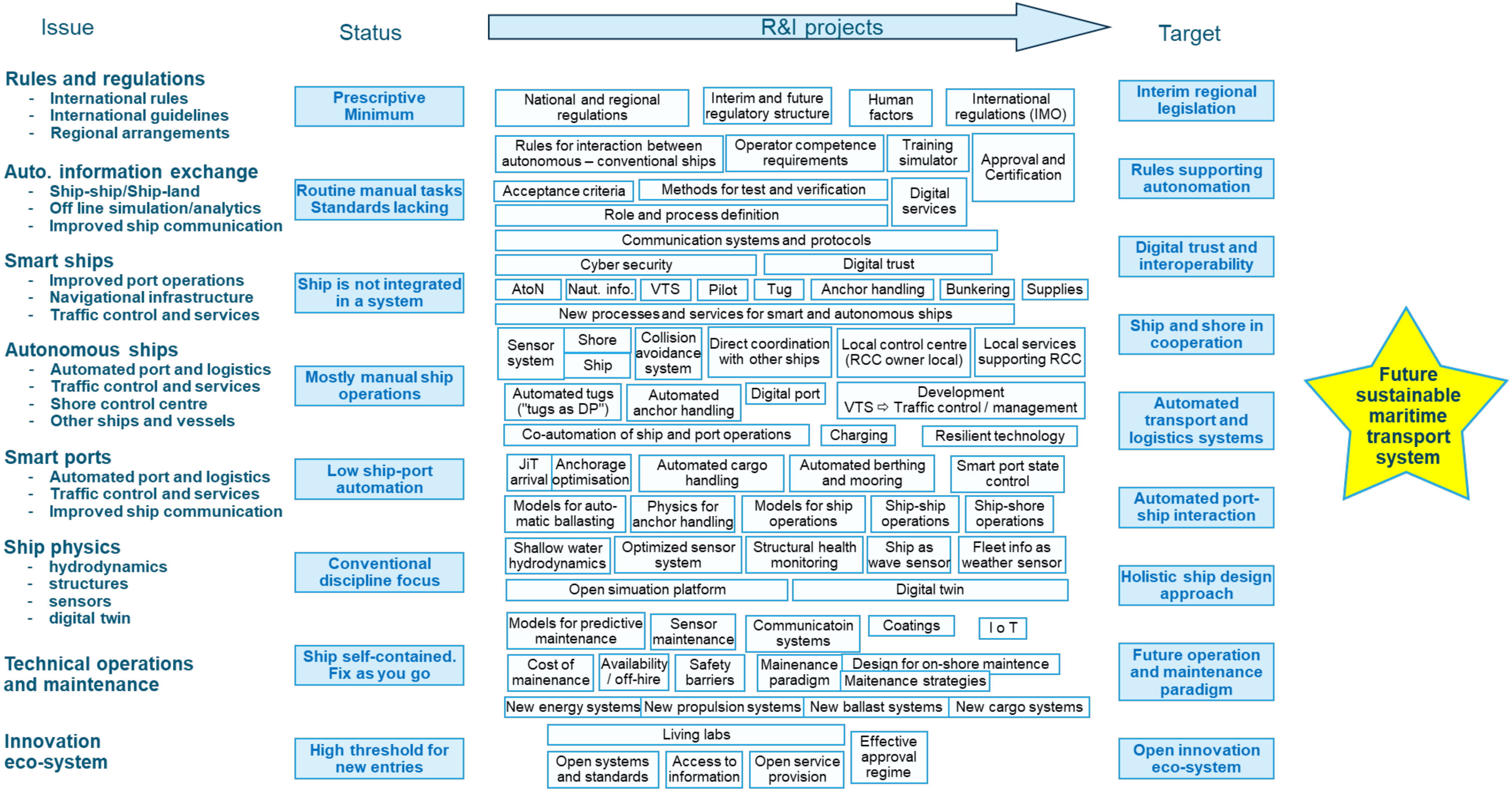
Norway Trade Mission	Singapore Maritime Institute
The Research Council of Norway	Agency for Science, Technology and Research

R&D Road-Map towards
Smart and Autonomous Maritime Transport Systems



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