AUTOSHIP

Autonomous Shipping Initiative for European Waters

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1. LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviation	Definition
ABS	American Bureau of Shipping
AI	Artificial Intelligence
AIS	Automatic Identification System
ANS	Autonomous Navigation System
AO	Automatic Operation, see section 9.7 for details
APAC	Asia/PACific region
AR	Augmented Reality
BV	Bureau Veritas (AUTOSHIP partner)
CA	Constrained Autonomy, see section 9.7 for details
CCNR	Central Commission for the Navigation of the Rhine
CDNI	Convention on the collection, Deposit and reception of waste generated during Navigation on the Rhine and other inland waterways
CEF	Connecting Europe Facility
CEMT	Conférence Européenne des Ministres des Transports / European Conference of Transport Ministers
CEVNI	The Code Européen des Voies de la Navigation Intérieure (CEVNI; European Code for Navigation on Inland Waterways) is the European code for rivers, canals and lakes in most of Europe.
CLL	International Convention on Load Lines
CLNI	The Strasbourg Convention on the limitation of liability in inland navigation
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
CN	China
CONOPS	CONcept of OPerationS
Deep-sea shipping	**Deep-sea shipping** refers to the maritime transport of goods on intercontinental routes, crossing oceans; as opposed to **shortsea shipping** over relatively short distances. See:

Abbreviation	Definition
	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Deep_sea_shipping
DFFAS	Designing the Future of Full Autonomous Shipping
DNV	Det Norske Veritas
EC	European Commission
ECDIS	Electronic Chart Display and Information System
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation vessels
EU	European Union
EV	Electric Vehicle
FA	Full Autonomy, see section 9.7 for details
Fallback	A designed operational state that can be entered through a fallback function when it is not possible for the autonomous ship system to stay within its operational envelope (ISO/TS 23860:2022).
GHG	GreenHouse Gases
GNSS	Global Navigation Satellite System
HHI	Hyundai Heavy Industries
HiNAS	Hyundai intelligent Navigation Assistant System
H2020	Horizon 2020
IA	Innovation Action
ICT	Information and Communication Technology
IDS	Intrusion Detection System
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
IMS	Intelligent Machinery System
INS	Integrated Navigation System
ISO	International Standardisation Organisation
IWS	Inland Waterways Shipping

Abbreviation	Definition
IWW	Inland WaterWays
JP	Japan
KET	Key Enabling Technology
KR	Korea
LISCR	Liberian Registry
LNG	Liquid Natural Gas
LOLO	Lift On Lift Off – cargo that is lifted onto the ship and off from the ship
LR	Lloyds Register
MASS	Maritime Autonomous Surface Ship
MBR	Maritime Broadband Radio
ML	Machine Learning
MLC	Maritime Labour Convention
MoU	Memorandum of Understanding
MRC	Minimal Risk Condition
MSC	Maritime Safety Committee
NK	Class NK
Operational envelope	The conditions and related operator control modes under which an autonomous ship system is designed to operate, including all tolerable events (ISO/TS 23860:2022).
OA	Operator and Automation, see section 9.7
OE	Operator Exclusive – see section 9.7
PESTLE	Political, Economic, Societal, Technological, Legal, Environmental
PNO	Ciaotech Srl (AUTOSHIP partner)
PS	Performance Standard
PU	Periodically Unattended bridge, see section 9.7 for details
RC	Remote Control autonomy level, see section 9.7 for details

Abbreviation	Definition
RCC/ROC	Remote Control Centre, often also called ROC (Remote Operation Centre) where the latter also implies that responsibilities related to planning operations, maintenance activities and logistics, could be included.
RCN	Research Council of Norway
RIA	Research and Innovation Action
RORO/ro-ro	Roll On Roll Off – meaning cargo that is rolled onto the ship and off of the ship, as opposed to LOLO.
ROV	Remotely Operated Vehicle
RPNR	Police Regulations for the Navigation of the Rhine
RSE	Regulatory Scoping Exercise (IMO, 2021)
RTI	Request To Intervene is an alert issued by the automation system notifying the onboard crew, or RCC operators, to get to the control position and take over control within a pre-defined time. This is related to Constrained Autonomy CA
R&D	Research & Development
SA	Situational Awareness
SAR convention	Search And Rescue convention by IMO
SAS	Safety and Automation System
SFI	Senter for Forskningsdrevet Innovasjon (Center for research driven innovation)
Sheltered water shuttles	**Sheltered water shuttles** are relatively small ships operating at relatively low speeds in coastal sheltered waters and limited operational areas with limited operational complexity.
Shortsea shipping	**Shortsea shipping**, abbreviated as **SSS**, is the maritime transport of goods over relatively short distances, as opposed to the intercontinental cross-ocean **Deep-sea shipping**. For more details see: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Short_sea_shipping_(SSS)
SOLAS	International convention for the Safety Of Life At Sea
SSR	Sherpa System for Real ship
SSS	ShortSea Shipping

Abbreviation	Definition
STCW	Standards of Training, Certification and Watchkeeping
STF	SINTEF Ocean AS (AUTOSHIP partner)
SVAN	Safer Vessel with Autonomous Navigation
TCOMS	Technology Centre for Offshore and Marine, Singapore
tkm	Ton-kilometre unit measure for the transport of one ton for one kilometre
TMC	International Convention on Tonnage Measurement of Ships
Tolerable events	A technical or operational event for which there is a designed response that keeps the system within its operational envelope (ISO/TS 23860). Note: A tolerable event includes events that are part of routine operations as well as events that are not considered part of normal operation but occur in practice as a result of different operational contexts (e.g. heavy weather, damage, failures, reduced communications capabilities, operator errors, etc.).
TRL	Technology Readiness Level
UNCLOS	United Nations Convention on the Law of the Sea
Uncrewed	Ship with no crew onboard (ISO, 2022)
Unmanned	Ship with no humans onboard (ISO, 2022)
USTRAT	University of Strathclyde (AUTOSHIP partner)
VAT	Value Added Tax
VDES	VHF Data Exchange System
VHF	Very High Frequency
VTS	Vessel Traffic Services
ZULU	Zulu Associates (AUTOSHIP partner)

2. EXECUTIVE SUMMARY

The AUTOSHIP project develops Key Enabling Technologies (KETs) for autonomous ships to TRL7 and will perform a full-scale demonstration of autonomous operations in a real operational environment for one shortsea shipping (SSS) case and one inland waterways (IWW) case. These KETs will then be used onboard the Yara Birkeland and ASKO ferries, and the goal is unmanned commercial operations within 2025. This will be an important milestone in the development of autonomous shipping, but to take the next steps towards a large-scale uptake of autonomy in the market, and ultimately in large-scale intercontinental maritime logistics is a challenge.

The AUTOSHIP project has developed a roadmap that provides some answers to this challenge, and this report documents the work in AUTOSHIP Task 8.2 *Roadmap for intercontinental implementation* and constitutes the deliverable D8.2 *Roadmap for Autonomous ship adoption and development*. The objective for the task is to develop a generalised roadmap for implementation of autonomous ships in large scale intercontinental maritime logistics. This is presented in section 3, while the work leading to the roadmap is documented in subsequent sections of the report.

The main results from the work are that firstly we find it likely that developments can be seen as progressing in four main segments; the shortsea *Sheltered water shuttles* which are relatively small ships designed for specific operations (including specific business cases), operating at low speeds in national limited areas at relatively low operational complexity (maintenance and operation is less of a challenge since time between ports is typically in the scale of hours – the vessel is always near land), the *Inland waterways* segment which includes both national and international operations in canals and rivers, the S*hortsea shipping* segment which includes international and national voyages over medium to long distances (one or more days), and areas of higher operational complexity (more traffic), and *Deep-sea intercontinental* segment which represents ships connecting continents (one or more weeks) and which typically are big high value assets.

Secondly, we believe that the first unmanned operations will appear in *Sheltered water shuttles*, immediately followed by *Inland waterways*, while *Shortsea shipping* will appear later, and *Deep-Sea intercontinental* last. We also believe that *Inland waterways* and *Sheltered water shuttles* developments will progress more or less in parallel the next ten to fifteen years, but that developments in *Inland waterways* will be a bit quicker and that *Inland waterways* may reach full autonomy (with RCC for recovering from fallbacks) first, due to a less complicated regulatory picture. In *Shortsea shipping* we expect the technological development to follow *Sheltered water shuttles* and *Inland waterways*, but that regulatory and maintenance related challenges, and standardising port interfaces, will constrain the development steps for quite some time to come. We expect that the technology will be used for (reduced) crewed ships operating with periodically unattended bridge, before unmanned operations are possible. Fully autonomous operations (with RCC for fallback recovery) will only be possible in *Shortsea shipping* after new COLREGs are in place[1]. For *Deep-sea intercontinental* the same constraints as for *Shortsea shipping* applies, in addition to higher investment risk due to higher asset value implying that extensive experience is required to establish significant trust before autonomy is used to realise unmanned ships. In addition, maintenance related issues will likely take a longer time to solve for *Deep-Sea intercontinental* than for *Shortsea shipping*.

Thirdly, and finally, we believe that the main constraining factors for the development steps must be solved by an active national and international public policy environment, building a strategy for forming policy actions that facilitates each development step. A more detailed discussion of the results and the roadmap illustrations are provided in section 3.

The roadmap was presented and discussed with the AUTOSHIP and AEGIS strategic advisory boards. In addition, a survey to collect stakeholder evaluation of our roadmap was distributed to both Strategic Advisory boards, as well as to main contacts in relevant Horizon projects. The respondents were asked to rate the key elements of the roadmap on a scale of 1 to 5 where 1 means “completely disagree”, 3 means “50/50” or “neither agree nor disagree”, and 5 means “completely agree”. All ratings had an average above 3, which we consider a good result indicating that our roadmap was well received and in general supported by most respondents. The detailed results of the survey with a discussion and information on how the results (and discussions) led to updates, are found in appendix A in section 14.

[1] This relates to our opinion on limitations within AI and Machine Learning, leading to our assumption that compliance to COLREGs cannot be automated for all possible scenarios. See section 3.1.1.

3. THE AUTOSHIP ROADMAP: HIGH-LEVEL OVERVIEW

The AUTOSHIP roadmap to large scale international maritime logistics (including inland waterways) is developed as three main components. First, we present the technological development steps that must be made. Then we present the high-level realisation roadmap where the main development steps in terms of uptake in four main sectors are projected. Then, finally, we present the constraints that must be overcome to facilitate the realisation roadmap, and the policy actions required to remove the constraints.

3.1. ASSUMPTIONS AND LIMITATIONS

The roadmap presented in this summary is our prediction of generalised developments on a high-level. It is our best-guess predictions based on the information that is available to us. This means that we do not claim that the roadmap is an absolute prediction, and that we do expect to see applicational cases deviating from our predictions. It also means that we focus on what we believe are the most important factors in the summary, while more detailed discussions are found in the subsequent sections of the report. Nevertheless, the roadmap does provide proposals for who we can achieve targets for accelerated uptake of autonomy.

Definitions related to autonomy are based on (ISO, 2022). Other definitions are available and commonly used, such as (CCNR, 2018), however, to avoid confusion in the summary section, we have not distinguished between e.g., definitions commonly used in maritime and in inland waterways, and stick to one set of definitions throughout the discussions.

As the goal of this study is to investigate the future developments of autonomous unmanned ships, including the steps along the way, the discussions include autonomy levels such as remote control, which makes unmanned ships possible to realise, but which business case is perhaps not that good.

Digitalisation in the logistics chain is a pre-requisite for increased automation and autonomy, however, with the speed of developments within that area, we do not foresee this as a constraining factor to the general developments within autonomous ships. This topic is therefore not discussed in detail.

Scope limitation for the study is elaborated in section 4. One important limitation is that we consider cargo ships only. We do recognise that developments within other sectors, such as USVs, ferries, and Naval ships, will have synergies with developments within cargo ships, however these sectors have not been studied in detail except a few commercial initiatives that are discussed in the development status sections.

Part of the roadmap is the suggestions for policy actions. In this part we discuss, amongst other things, the business case dependency to funding. In short, the need for funding relates to autonomous ships depending on certain services, while the providers of such services depend on a certain number of autonomous ships to have a sustainable market. This creates a high investment risk for both potential service providers and autonomous ship owners, in most cases. It is our belief that public funding can play an important role in this picture. It should be noted that we take the perspective of large-scale uptake mainly from a European perspective in our recommendations for funding to accelerate uptake. This is because the EU is a potential provider of such funding, while we find it unrealistic to establish funding schemes on a global level. Furthermore, we believe that accelerating the European uptake of autonomy will also accelerate developments in general, which in the longer term will enable uptake in other regions.

We do recognise that it is possible that larger actors operating in liner trades may find business cases that includes regions where no funding regimes are available viable due to having the financial muscles to do large-scale investments (they often own terminals in both ends of the route and can develop these in parallel with the ships). It is also possible that funding for parts of large-scale networks is sufficient to realise the full network. We therefore believe that a European funding scheme can ultimately contribute to the acceleration of global uptake.

3.1.1. The limitations of AI and Machine Learning, and the implications for COLREGs

The interactions between ships at sea are regulated through COLREGs to avoid accidents and collisions. COLREG is a well written set of rules that allows navigational officers to use their best judgement and direct communication with other ships to find safe solutions to complex situations. This, however, means that COLREGs do not provide exact and prescriptive rules for all situations, as the concept of "good seamanship" is an essential part of COLREGs.

Computers are excellent at executing actions based on unambiguously defined rules. They are, however, notoriously bad at improvising. For situations that are well defined, rule-based systems e.g. fuzzy logic, can be applied. For situations that are outside of the rule set, however, such systems will not perform well. Ships are often involved in complex multi-vessel encounter situations, that rely on the concept of "good seamanship" to resolve the situation. Such situations are not conducive will rule-based systems. This makes complex interactions between ships problematic to solve for autonomous ships and is one of the key reasons why RCCs are perceived to be an essential part of autonomous ship systems for now.

Some look to Artificial Intelligence (AI) and Machine Learning (ML) for a solution to automating the interactions between ships. However, training AI and ML models to handle all possible encounter situations is very difficult. This is due to inherent limitations in machine learning related to the size of the artificial neural network and the data set that has been used to train it. Apart from the inherent limitations related to how much information you can store in a given artificial neural network; it is generally impossible to train ML algorithms on all possible scenarios a vessel might encounter. This would require a virtually infinite data set, comprising all variations of complex multi-vessel encounter situations.

Through unsupervised learning, ML models can interpolate or extrapolate the observed situation based on those it has encountered in the training set. In many cases, the ML models may return actions that resolve the interaction situation in a safe and efficient manner. However, in some cases the situation may be in a region that the model is unfamiliar with. This can result in an interpolation between several otherwise meaningful actions to yield a spurious, unsafe action. Alternatively, the situation may be far outside the domain of the training data, and the resultant extrapolated action will be entirely meaningless. Such actions can potentially be catastrophic. It is, therefore, difficult to predict what the actions taken for situations outside the data set will be, or even if they will be safe. Even if one recognised that the training set is limited and opted for a solution where the automation handed over control to the RCC for cases outside the training data set, it is a fundamental problem for ML algorithms to recognise that the data set is insufficient for the case at hand. As such, there is no guarantee that the ML algorithm detects that it is not capable of handling the situation. This leaves the safety of the ship to chance in many situations.

Deep learning-based AI models already have useful applications in tasks like object classification, but for critical operations, rule-based reasoning is in our opinion required. This implies a need for updating COLREGs (as elaborated in section 9.11.2) to make it more suitable for automated reasoning. Updating COLREG is not straight forward, in some people’s opinion potentially even infeasible, and will as a minimum require a long time. This is also why we believe it will take a correspondingly long time to realise full autonomy for maritime ships.

3.2. TECHNOLOGICAL DEVELOPMENT STEPS

Before we present the high-level realisation roadmap, we will present our view on the most relevant levels of ship automation and what they entail in terms of technological developments. This is given as our proposed *Main technological development steps* in Figure 1. These technological development steps represent what we find to be the most likely technological concepts deployed onboard ships, and how they will evolve. The technological development steps are based on combinations of automation and human control and are based on the autonomy levels that are discussed in detail in (Rødseth, Wennersberg, & Nordahl, 2022):

- **AO: Automatic Operation** – Examples could be dynamic positioning, automatic berthing, or automatic crossing, where automation performs operations under continuous supervision from the crew. Though functions are executed automatically, all decisions to make changes (such as re-routing or deviating from a plan) are made by the crew (operator of the automation system).
- **RC: Remote Control** – In this case the ship would be continuously supervised from shore. This normally uses AO autonomy level automation with interface for remote control. Though functions are executed automatically, all decisions to make changes, such as re-routing or deviating from a plan, are made by the RCC operator. Furthermore, when used to realise unmanned ships, the ship systems must be capable of maintaining safety in the event of loss of communication with the RCC, which includes the initiation and execution of fallbacks.

- **PU: Periodically Unattended** – The ship can steer itself automatically for extended periods, e.g., in open waters and calm weather. Crew is available onboard to handle more complex situations, but can be away from the controls and, possibly, at sleep during night-time. This normally uses constrained autonomy to enable periods of unattended operations, and crew is alerted in time to gain situational awareness and take over control in case a situation that the automation cannot handle is developing. Certain decisions are made by the automation, and there are clear definitions of the criteria for what decisions automation can make.
- **CA**: **Constrained Autonomy** – Uncrewed operation with constrained autonomy onboard but with operators in RCC that can handle more complex situations. This corresponds to PU but without crew onboard. Certain decisions are made by the automation, and there are clear definitions of the criteria for what decisions automation can make.
- **CA standard RCC**: - Same as CA, but with standardised interfaces and interactions between the autonomous ship and the RCC, and with standardised operator-automation interfaces. This makes it possible to transfer the control of an autonomous ship from one RCC to another, e.g., making a second-hand market for autonomous ships easier to establish and by that reduce risks related to investments. Certain decisions are made by the automation, and there are standardised definitions of the criteria for what decisions automation can make.
- **FA**: **Full autonomy** – The ship handles all foreseeable situations by itself and there is no crew neither on ship nor in RCC that has any responsibility for any function within the intended design. RCC operators can however be involved in fallback handling and for recovery from fallbacks. All decisions are made by the automation systems on board.

Autonomy levels are discussed in more detail in section 9.7. Notice that we added *CA standard RCC* as a technological development step (which is not an autonomy level found in (Rødseth, Wennersberg, & Nordahl, 2022)) because this will make it much easier to move autonomous ships from one operational setting to another - which may require a change of the RCC - and by that create a more realistic second-hand market for autonomous ships. We find this to be an important development step for reducing investment risks and is as such included in our roadmap.

While many experts point to navigation and to keeping critical technical systems, such as energy production, steering and propulsion operational during longer voyages (maintenance), as being the most difficult to automate, it is clear that all onboard systems must be automated and/or transferred to the RCC to realise a fully unmanned ship. This also includes the port call related processes that require assistance from crew onboard. We therefore consider the technological development steps along five axes, as given in Figure 1. These five axes represent main technological areas that are essential for navigation (*autonomous navigation* and *RCC*) as well as other operations and maintenance (*Safety and automation systems*, *maintenance*, and *port call interfaces*) of autonomous ships.

	AO	RC	CA	CA Standard RCC	FA
Autonomous navigation	Operator and decision support	Conventional control systems with remote control, sensors for watch keeping, operator and decision support	Situational awareness. Defined automation capabilities and model for operator – automation interface	Same as previous, standard interface to RCC.	Implementation of internationally accepted rules for interactions (COLREGS). Must handle full operational envelope
RCC	Supports remote monitoring	Supports remote control	Defined model for operator – automation interface	Standard model for operator – automation interface	Only support for fallback handling
Safety and automation systems	Conventional with interface to RCC	IMS, predictive maintenance, redundancy support if relevant	Situation awareness own ship. Defined automation capabilities, model for operator – automation interface	Same as previous, standard interface to RCC.	Must handle full operational envelope
Maintenance	By crew	Boarding teams, new maintenance regime and predictive maintenance	Same as RC	Same as RC	Same as RC
Port call interface	Conventional	Functions that cannot be performed by personnel from land must be automated	Same as RC	Same as RC	Same as RC

Figure 1 Main technological development steps

We consider the technology today to be *AO* where technology related to navigations is mostly conventional, but where operator and decision support is increasingly being adopted. Examples are auto-crossing and auto-docking which are automated functions that require continuous supervision by the bridge crew, but where the function is executed automatically, or automatically generated re-routing suggestions, such as to avoid collision, but where the crew must perform the actual change in route. All communication with other ships or stakeholders is performed by the crew. Maintenance is performed during sailing, when needed. Current safety and automation systems are already highly automated and unattended for most of the time already (in practice, close to autonomy level CA). A few RCCs are in operations, but these are mainly for monitoring ship-status and, in some limited cases in inland waterways, for remote control of barges. Port call interfaces, such as mooring and cargo handling, are conventional, meaning, they depend on crew to control and monitor, and to do some manual actions like fastening mooring lines to bollards.

The next technological step will be *RC* uncrewed ships where technology is adapted to support remote control with continuous attention from the RCC. In this step, navigation is performed by conventional control systems that allows remote control (intervention by the operator) in combination with sensors for watch keeping and the transmittal of quite extensive amounts of data between the uncrewed ship and the RCC. This means that the RCC now supports remote control of all ship systems, that the safety and automation systems (SAS) are controlled and monitored by an IMS, that predictive maintenance systems are in place, that the SAS supports redundancy where relevant, and that the ship automation can maintain safety even if communication is lost (though normal operation will probably be aborted). Operator and decision support systems are still in use, but the RCC operator makes all navigational decisions. Maintenance is performed by boarding teams and new maintenance regimes are in place, based on predictive maintenance. Functions related to port call interfaces which cannot be performed by personnel from land are now automated. It should however be noted that this does not necessarily imply that all functions are automated. As an example, cargo handling could probably be handled by land-based crew for most unmanned ships (assuming efficiency and cost constraints are not considered).

The next technological step is then *CA* (and *PU* enabled by CA technology*)* where technology is adapted to support constrained autonomy where the RCC (or in the case of *PU*, the crew) only intervenes after an alarm is issued. That is, the automation is in control for most of the time. Navigation is performed by the automation, and the ship is equipped with situational awareness for the navigational environment, as well as for its own internal state and capabilities. Automation capabilities and the model for operator-automation responsibility division, and under what conditions these apply, as well as operator-automation interfaces, are defined.

The next technological step is *CA, standard RCC* where most technology is as for the previous step, but where interfaces to the RCC and operator-automation interfaces are standardised. Currently, approval is tightly related to the specific RCC and operational area for its intended operations. Hence, the ship is not approved for operations in other areas or under the control of other RCCs, without a new round of approval. Standardising RCCs, interfaces, operational conditions, and RCC and ship capabilities, separates approval of RCC and approval of putting an autonomous ship into operation in a given area. This allows autonomous ships to be moved between areas and being under the control of different RCCs, and this is particularly important for creating a second-hand market for autonomous ships as they are no longer locked to a specific RCC or area. This substantially reduces the risk of investments in autonomous ships. This step is also important for accelerating the general uptake of autonomy as it will bring down costs, and time, for building new autonomous ships and putting them into operation.

The final technological step is *FA* where technology (and regulations) has reached the point where the ship is fully autonomous and all functions and situations that the autonomous ship is designed to handle are executed by the automation system. The autonomous navigation systems implement internationally accepted rules for interactions (COLREGs) and handles the full operational envelope (Rødseth, Wennersberg, & Nordahl, 2021). All other automation systems are also autonomous and handles the full operational envelope. The RCC is still a vital part of the autonomous ship system, however, in this step it is only involved in fallback handling and recovery from fallbacks.

An interesting observation made in this work is that the connectivity requirements in terms of the type and amount of transferred data, and latency, is gradually reducing with increased technological development from left to right in Figure 1. This means that once connectivity is solved for the lower technology levels, it is also solved for the remaining technology steps.

The timeline for realisation of the technological steps depends on technological maturity, the regulatory framework, standardisation, policy, and economic aspects. This will be discussed in the following sections.

3.3. HIGH-LEVEL REALISATION ROADMAP

With the technological steps defined, we can present our high-level realisation roadmap as given in Figure 3. The high-level realisation roadmap is split into four main groups of vessels, or shipping segments. The first is the *Sheltered water shuttles* which are relatively small ships designed for specific operations (including specific business cases), operating at low speeds in national limited areas at relatively low operational complexity (maintenance and operation is less of a challenge since time between ports is typically in the scale of hours – the vessel is always near land). Examples are the Yara Birkeland (Kongsberg Maritime, 2022) and the ASKO ferries (FleetMon, 2022). The second segment is *Inland Waterways* segment which includes both national and international operations in canals and rivers. Examples are the initiatives by ZULU Associates (ZULU Associates, 2023) and SEAFAR (SEAFAR, 2023). The third is *Shortsea shipping* which includes national shortsea over medium to long distances (one or more days), and international shortsea shipping (e.g., intra-EU shipping), with higher operational complexity than *Sheltered water shuttles*. The final segment is *Deep-Sea intercontinental* which represents ships connecting continents (one or more weeks) and which typically are high value assets.

Note: The roadmap considers cargo vessels only. Excluded segments such as e.g., Naval units, which are less affected by constraining factors such as national regulations and permits, will possibly develop more rapidly.

The roadmap in Figure 3 is built up by development steps within each segment, over intervals of 5 years. The bottom arrow shows the final year in each five-year interval. Five-year intervals have been selected as it gives a suitable granularity to the foresight but should not be understood as an absolute prediction of when a certain type of ship is actually realised.

Each cell in the roadmap is built up as shown in Figure 2. The top line shows the expected development level in terms of ship type and operational concept. The second, blue line shows the autonomy level as explained in the first bullet list of section 3.1. The bottom, green line shows the main constraining factors that we expect will have been overcome at this stage.

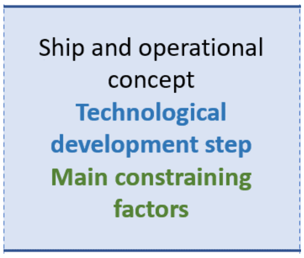

Figure 2 High-level realisation roadmap cell content legend

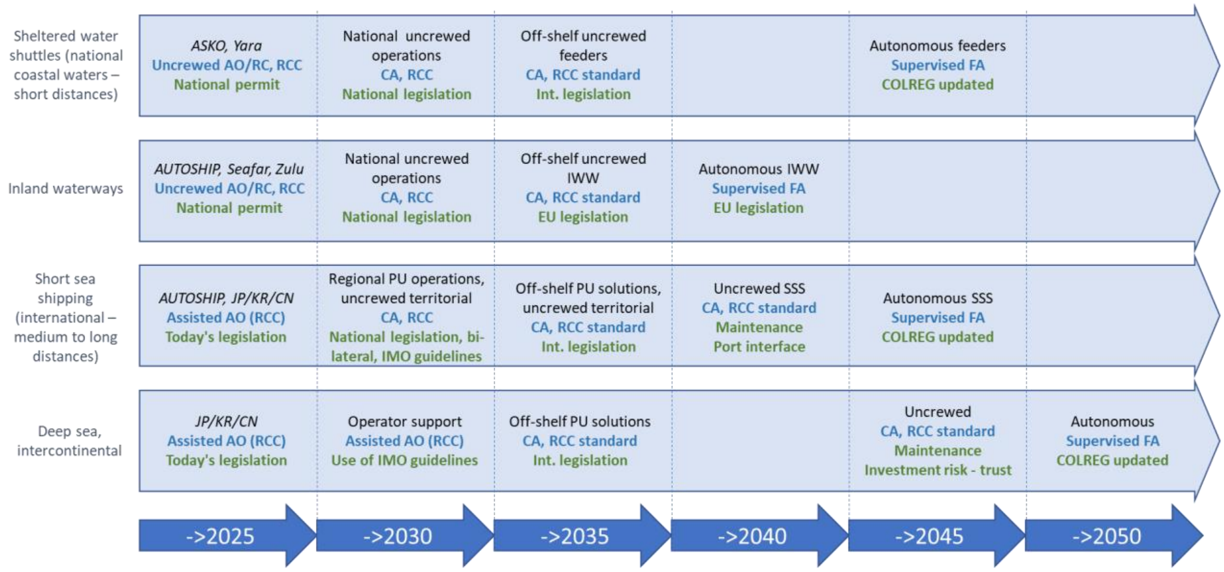

Figure 3 High-level realisation roadmap

Up until 2025 we will first see technology demonstrations in real operations, then we will see the first uncrewed ships enter operation, in sheltered water shuttles and on inland waterway. In both segments, the technology will be at the *RC* step and used to realise uncrewed ships. The main constraining factor are regulations and national permits that will be required to allow the operations. In shortsea and deep-sea, there have been full scale demonstrations of autonomous technology, including navigation at the *RC* step in Japan, Korea, and China (JP/KR/CN), and we will see more such demonstrations, e.g., by the AUTOSHIP project in 2023. However, operations in these segments will remain at the *AO* level and main advancements will be operator and decision support to increase efficiency and safety. The main constraining factor is legislation, but probably also economy and perceived risk associated with the required investment.

Then, **from 2025 until 2030**, we will see national uncrewed operations with technology at the *CA* step in both sheltered water shuttles and inland waterways. While in shortsea we will see the first periodically unattended (*PU*) operations, also with technology at the *CA* step. We may also see some uncrewed operations in some limited cases with short distances in territorial waters. This is because legislation and maintenance issues are likely not solved, preventing uncrewed operations in general for SSS in this period. The main constraining factor to overcome for these segments in this period is national legislation for national operations and establishment of bi-lateral agreements between involved nations for international operations, with the use of IMO guidelines as an important step towards overcoming this constraint. In deep-sea we will see individual concepts using more and more automated functions, and autonomy related equipment, however, the technological will be at the *AO* step in this period also, with international legislation as the main constraining factor and the initial use of the new IMO guidelines as an important step towards overcoming this constraint.

From 2030 until 2035, we expect "off-shelf" technology and uncrewed vessels for both sheltered water shuttles and inland waterways, enabled by technology reaching the *CA standard RCC* step. More and more autonomous ships are being put into operation in these segments and they are starting to take over market shares. We also expect international operations in inland waterways, and though sheltered water shuttles still operate over shorter distances and limited areas, we expect an increased market as approval may be based on international regulations. International, and for inland waterways mainly EU, legislation will thus be the most important constraining factors to overcome. For shortsea we expect more uncrewed operations in limited cases with short distances in territorial waters. We also expect "off-shelf" periodically unattended (*PU*) concepts for the shortsea and deep-sea segments, enabled by technology reaching the *CA standard RCC* step, where international legislation will be the most important constraining factor to overcome.

From 2035 until 2040, we expect that the main developments are that inland waterways moves to autonomous operations enabled by the technology taking the *FA* step. This means that we expect the first fully autonomous ships in inland waterways in this period, where fully autonomous means that the ships handle all functions and operations and are supported by RCC for fallbacks and recovery only. Again, the EU legislation will be the main constraining factor. For shortsea we expect that uncrewed operations in general becomes possible, enabled by international legislation having been overcome and the technological developments in the previous period. The main constraining factors to overcome will be maintenance and port interfaces. These voyages will be for extended periods, not possible under contemporary maintenance schemes. Possibly, new, less maintenance intensive propulsion systems are needed, in combination with technology for predictive maintenance and new maintenance schemes. Shortsea port interfaces must also be made ready to accept port calls by uncrewed ships, which requires major investments.

From 2040 until 2045 we expect autonomous sheltered water shuttles and shortsea ships, enabled by the technology taking the *FA* step, to appear. The main constraining factor to overcome will be updated COLREGs to enable safe interactions between conventional and fully autonomous ships by rules defining unambiguous actions for all conceivable scenarios. See sections 3.1.1 and 9.11.2 for more details. We also expect to see the first uncrewed deep-sea ships in this period, though maintenance needs for long voyages and gaining stakeholder trust to reduce the perceived investment risk, will be significant constraining factors that must be overcome in this period.

Finally, we believe that fully autonomous deep-sea ships will not appear before **around 2050**. Once again, COLREGs, maintenance, and gaining trust at the investor and key stakeholder level, will be the constraints.

3.4. CONSTRAINTS AND POLICY ACTIONS

The relations between the main developments predicted in the high-level realisation roadmap, constraints, and required policy actions are quite complex. Nevertheless, in the following, we will present our opinions on the main constraints, in some more detail, and the main policy actions that we believe are needed to stimulate the removal of the constraints and thus the realisation of the high-level roadmap, for each period. We believe that the main constraints are found within regulations, standardisation, business models, economy, and societal acceptance. In short, to make an investment decision in an autonomous ship, it must be technically possible to realise the ship, it must be legal to operate it, necessary infrastructure and supporting services must be available at an affordable cost, the price must be sufficiently low to make the investment profitable, and there must be a viable business model for operating the ship and for providing the required services to the autonomous ship. As will be shown in section 5, autonomous ships are desirable from a societal perspective, but in our opinion, it is likely that some policy actions, such as closing financial gaps in an early development phase, are needed to realise autonomous ships to reap these societal benefits. The main constraints within these categories are given in Figure 4.

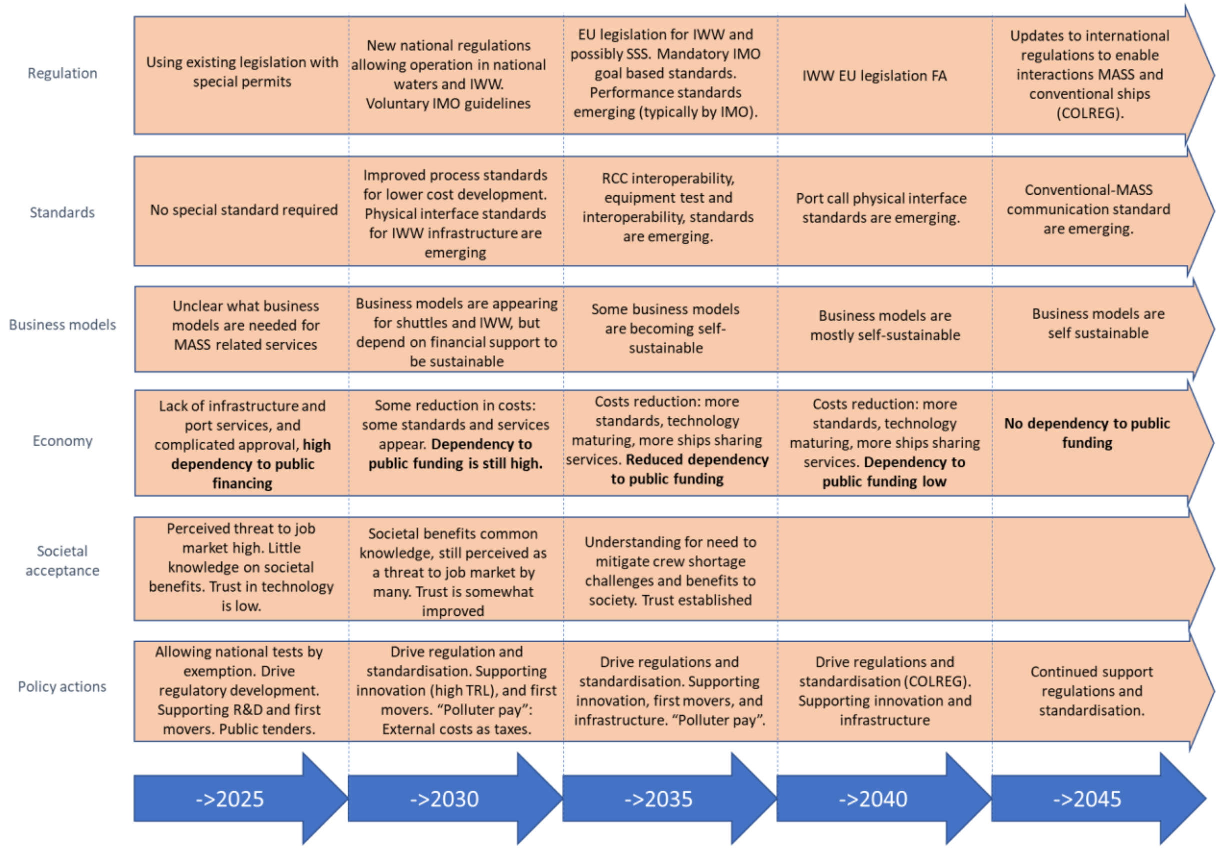

Figure 4 Constraining factors to development steps, and policy actions

If we first consider the constraints related to regulations and standardisation, we believe that there are no constraints blocking the developments towards **2025**. In this period, policies need to allow national tests and operations by exemptions, and regulatory developments for the next phases must be in policy programs (such as new national regulations, or the IMO plans for a new MASS code).

If we move to the next development phase, that is from **2025 to 2030**, we believe that new national regulations allowing operation in national waters and inland waterways are needed, as well as the voluntary IMO guidelines. At the same time, we believe that improved, or perhaps new, process standards are needed to lower development costs, and that physical interface standards (e.g., for interactions with locks) for inland waterways needs to be emerging. Required policy actions in this period are supporting and driving international and national regulatory developments, and standardisation processes.

In **2030** to **2035**, EU legislation for inland waterways and possibly shortsea shipping is needed, as well as the mandatory goal-based IMO standards. Also, performance standards for KETs (Key Enabling Technologies) needs to be emerging. At the same time, standards for interoperability (ship-RCC, equipment-equipment, ship-ship), and for testing, needs to be emerging. Required policy actions for this period is the continued support and efforts to drive international and national standardisation and regulatory developments.

In **2035** to **2040**, EU regulations for fully autonomous inland waterways ships are needed, as well as port-call physical infrastructure standards. Required policy actions for this period is the continued support and efforts to drive international and national standardisation and regulatory developments. Particularly with focus on COLREGs and the standardisation of communication between autonomous ships and conventional ships.

In **2040** to **2045** updated international regulations to enable deterministic and safe interactions between autonomous and conventional ships (updated COLREGs) are needed. To realise this, we expect that a new communication standard between autonomous ship and conventional ship is needed to safely exchange plans and intentions. Required policy actions for this period is the continued support and efforts to drive standardisation and regulatory developments related to COLREGs and communication between autonomous ships and conventional ships, such that these are finalised in this period.

Another area where we find important constraints are business models and economy. Initially, towards **2025**, it is unclear what business models are needed to realise the various services that autonomous ships will depend on. Furthermore, the lack of infrastructure and port services that autonomous ships will depend on, in addition to a complicated and costly approval process, will in most cases hinder investments due to too high costs. This is because potential investors will have to make investments beyond merely the ship itself. The investments we have seen thus far are significantly supported by public grants, and we believe that in this period, the realisation projects will depend on public funding. Required policy actions are therefore to continue to support research and development projects, and to provide funding to first-mover projects such that economic viability is ensured. Another possibility is to use public tenders to stimulate developments. Examples seen from e.g., Norway, where ferry tenders specify certain technology, like batteries or auto-mooring, shows how policy actions can be used to stimulate the initial growth of a new and socially desired market.

In **2025** to **2030**, we believe that the first business models for providing services to autonomous shuttles and inland waterways ships are appearing, but that they in many cases depend on financial support to be sustainable as the market is still immature. We will see some cost reduction in this period as some standards and services are appearing, however, economic viability is still highly dependent on public funding. Required policy actions are therefore to continue support to research and development, but with more focus on high TRL innovations, and to continue to provide public funding to first-mover projects. Public tenders are still a possible tool, and in addition, taxation schemes internalising external costs could be used to stimulate customers of transportation services to choose sustainable transportation modes, such as waterborne.

In **2030** to **2035**, we believe that some business models will start to be self-sustainable, that costs will continue to be reduced as more standards are appearing and technology is maturing, and more ships are sharing the autonomous ship related services. The economy of autonomous ships is still dependent on public funding but reducing. Required policy actions are to fund infrastructure, to continue funding of innovation, and continued policies for internalising external costs. Where funding infrastructure will probably be the most important action if large scale autonomous shipping is to be realised.

In **2035** to **2040**, we believe that most business models for providing services to autonomous ships are self-sustainable, and that costs are further reduced as more standards are in place and technology continues to mature. Another important factor for reduced costs is that more autonomous ships will be in operations, which means that more ships are sharing infrastructure and supporting services. The dependency to public funding in this period will probably be low, and possibly restricted to certain applicational areas or markets where the uptake is still low. Policy actions in this period should probably focus on funding infrastructure and innovation.

Finally, from **2040** to **2045**, we believe that business models will be self-sustainable, and that the economy of autonomous ships no longer depends on public funding.

Our proposal for public funding to balance out the economy of investments in autonomous ships is inspired by how Norwegian policy actions played a significant role in the large-scale uptake of electric cars in Norway. Several incentives were introduced through policy actions, ranging from direct economic incentives like the exemption from 25% VAT, and from road taxes and ferry charges, to access to the bus lanes or regulating rights to access to charging and funding charging infrastructure along the road network (Norwegian EV Association, 2023) (mer, 2022). The different incentives have been put into effect at different times, and some have been changed, removed, or relaxed as the uptake goal was getting closer to being achieved. As an example, investing in charging infrastructure was important to create the required coverage in an early phase, and significant economic incentives were needed to make people take the investment risk implied by new technology and a virtually non-existing second-hand market. But once these factors were no longer barriers, these incentives were removed or relaxed. This strategy is illustrated in Figure 5 and is based on a presentation by ENOVA (Leistad, 2023). The result of this policy is that in 2022 79.2% of the sold cars were electric, and that more than 20% of the registered cars in Norway were electric (Norwegian EV Association, 2023).

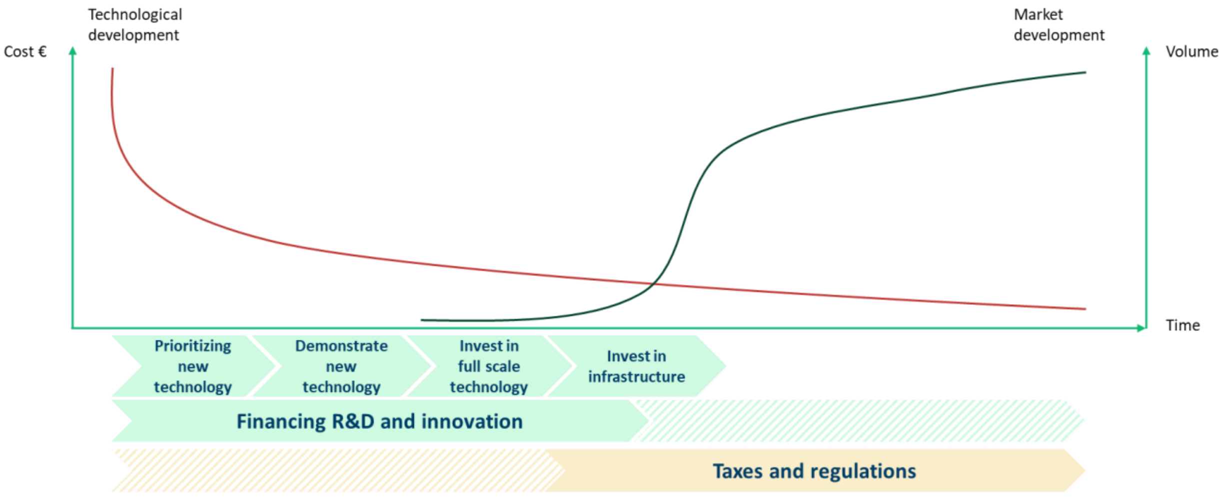

Figure 5 Illustration of the policy strategy for stimulating development and uptake of new technology, as presented by ENOVA (Leistad, 2023)

Similarly, we believe that a set of policy actions can be formed to accelerate the uptake of autonomy in shipping. Some proposals have been discussed in this section; however, other policy actions could also be conceived. And it is our recommendation that studies on the potential of policy actions to accelerate the uptake of autonomy are launched.

A prerequisite to forming such policies is that the society wants autonomous ships. Policies are, after all, intended to take care of the societies best interest. Convincing the general society is therefore important to enable the large-scale uptake of autonomy, and thereby to achieve large scale intercontinental autonomous maritime logistics. The AUTOSHIP project did a survey, published in (Theotokatos, Dantas, Polychronidi, Rentifi, & Colella, 2022), where it was found that not everyone are convinced that autonomous ships are needed. Furthermore, many seafarers fear that job security will be negatively affected, and it appears that the benefits of autonomous ships are not clear to everyone. This will likely be the status towards 2025, so dissemination to the wider society will be important in this period. Awareness of benefits, the growing deficit in recruitment of crew, and real-life demonstrations of the technology will be important.

From **2025** to **2030**, we believe that it should be possible to make the benefits of autonomous ships common knowledge, but we also believe that many will still perceive autonomy as a threat to jobs. Trust in the technology should however be increasing due to more realisation projects and full-scale demonstrators. Continued dissemination is needed, particularly focused on the challenges related to recruitment.

From **2030** to **2035**, we believe that it should be possible to establish an understanding for the need to mitigate crew shortage. By this time, it should also be more apparent as the predicted deficit in crew availability may have started to materialise in some countries and, unless many uncrewed ships are already in operations, impacts on logistics may have started to cause problems. As an example, Japan is already facing challenges with an aging population, and this is the main motivation behind the MEGURI 2040 initiative which aims for transforming the Japanese fleet to 50% autonomous by 2040 to tackle the lack of workers (The Nippon Foundation, 2022).

The work leading to the overview presented in this section is documented in the subsequent sections of this report.

4. INTRODUCTION TO THE DETAILED ROADMAP

The AUTOSHIP project has been developing technology and performed research to take significant steps towards the realisation of the first commercial autonomous ships. Technology is however not the only component that must be in place to bring about a large-scale change, such as uptake of autonomy in maritime logistics would be. This report investigates the key components that must be in place for a large-scale uptake of autonomy in maritime intercontinental logistics. What is the status? What are the constraining factors preventing the acceleration of uptake in the industry? And what can be done to remove the constraints?

4.1. PURPOSE OF THE ROADMAP

This roadmap is intended to give guidelines for implementation of autonomous ships in *large scale intercontinental maritime logistics*. The underlying assumption is that autonomy will increase maritime transport efficiency and bring about a host of benefits that are desirable for the society and the maritime industry. This is elaborated in section 5.

Large scale intercontinental maritime logistics is in the context of this report is understood as logistic chains moving large quantities of cargo between continents. This includes national distribution and consolidation of cargo, such as sheltered water shuttles and inland waterways barges, international distribution, and consolidation of cargo (such as shortsea feeder lines), and intercontinental transportation by cargo ships (such as container ships for deep-sea shipping). More details are given in section 4.3.1.

The roadmap will present our views on the likely high-level development steps towards realisation, discuss some of the key constraints limiting the progress and propose some policy actions that could remove these constraints.

4.2. DEFINITION OF THE AUTONOMOUS SHIP

For the purpose of the discussions in this report, the autonomous ship is understood as an unmanned (ISO, 2022) ship that is supported by an RCC. This is also coined *constrained autonomy*, which means that the ship can operate autonomously within certain limits (e.g., limited by traffic complexity). More specifically, per design, the operational envelope (Rødseth, Wennersberg, & Nordahl, 2021) defines all the autonomous ship functions, and a division of responsibility between automation and RCC operators, and under what conditions the responsibility division applies. A simplified example is that the operational envelope can define that the function “navigation” is executed autonomously as long as no more than *x* ships are within a distance of *y* nm, and that if this condition is not met, the responsibility for the function “navigation” is handed over to the RCC operator. This handover is not to be confused with initiating a fallback as it is the intended design for how the given situation is handled.

Fully autonomous ships are understood as ships where all functions under all conditions are executed autonomously by the automation systems. That is, the RCC is not part of the operational envelope. However, the RCC is still part of the autonomous ship system, but in this case, the RCC is only responsible for handling or recovering from fallbacks. Fallbacks are emergency measures taken when the situation is outside the operational envelope (the autonomous ship is not designed for handling the situation at hand).

If autonomous ships of other autonomy levels are discussed, this will be explicitly stated in the discussion. Definitions of autonomy levels are also discussed in more detail in section 9.7.

4.2.1. Definition of the autonomous ship system

An autonomous ship (regardless of the actual level of autonomy, as discussed in detail in (Rødseth, Wennersberg, & Nordahl, 2022)) does not operate in a vacuum. As a bare minimum, autonomous ships need terminal facilities for loading and unloading, mooring, solutions for remote monitoring and control (i.e., a Remote Control Centre), as well as supporting infrastructure related to communication technology, bunkering of energy, etc. In the context of the roadmap, the *autonomous ship system* is to be understood as an autonomous ship including RCC and other infrastructure as given in Figure 6.

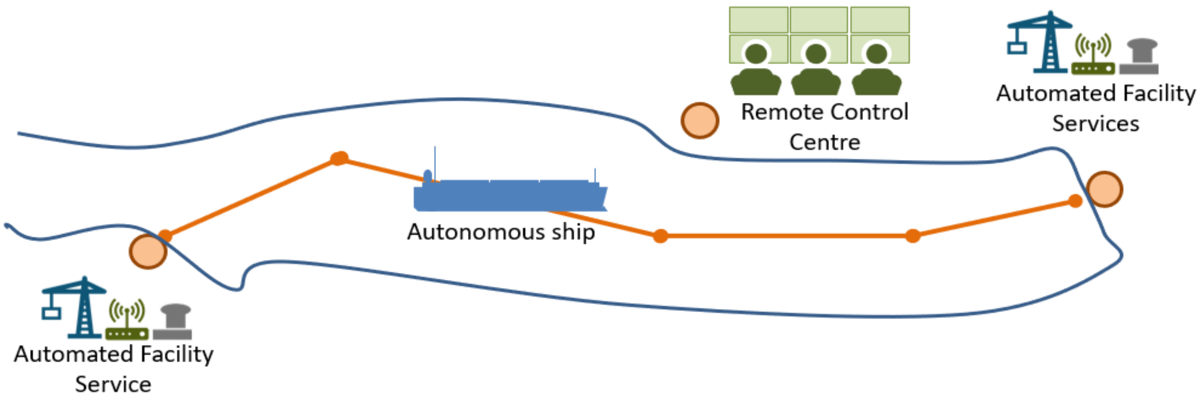

Figure 6: The autonomous ship system (source: (Wennersberg, et al., 2020))

4.3. SCOPE LIMITATION

The task for this deliverable is to create a roadmap for implementation of autonomous ships in large scale intercontinental maritime logistics. Our take on this task is to identify gaps and based on that form steps that must be taken and use these steps to form the roadmap. Identifying all possible gaps in this context is a virtually impossible task, so, we need to limit the scope to something manageable, while capturing the most important aspects. The following discussion will clarify the scope limitation.

The first limitation is that only cargo ships are considered and that the autonomous ship is the focus of the analysis. As an example, USVs, ferries, and Naval applications are not studied in detail, they are however, touch upon in section 11 as we do recognise synergies with the developments within other segments. The second limitation is that where this is relevant for the discussion, transportation is to be understood as liner transportation (e.g., of containers). The third limitation is that ports, cargo handling, terminal operations, transhipments between modes, automation, digitalisation of documents and the logistics related processes, will not be considered in detail. This is because these topics are not part of the scope of the AUTOSHIP project, however, some of these are relevant in parts of the discussion and will be touched upon briefly. The fourth limitation is *large scale intercontinental maritime logistics* as defined in section 4.1, and in more detail by the example in section 4.3.1.

4.3.1. The large-scale intercontinental logistics

To have a baseline for the analysis, we will define a large scale intercontinental maritime logistics chain operated by conventional ships and operated by autonomous ships.

The conventional intercontinental logistic chain (see Figure 7): large container ships connect China to Europe. When they arrive in Europe, a large number of containers are unloaded, causing hectic activity at the European deep-sea port (e.g., in Rotterdam). Some containers are transhipped to shortsea feeders that delivers the containers to coastal ports in e.g., Norway, where they are picked up by trucks and distributed to the end destination. In addition, truck transport from the European deep-sea port dramatically increases as thousands of containers are transported into the hinterland. This causes heavy road congestion, significant emissions and other external costs.

In the autonomous intercontinental logistic chain (see Figure 8)**:** Large autonomous container ships (but smaller than in the conventional case) connects China to Europe. When they arrive in Europe, the containers are transhipped to autonomous shortsea feeders and inland waterway barges. The shortsea feeders deliver the containers to hubs along the coast of Norway, where they are picked up by autonomous shuttles and delivered to smaller quays. In some cases, to the end customer, while often trucks will have to take then the last mile. The autonomous inland waterway barges distribute containers via the inland waterways network, also here, some truck transport is needed for the last mile. However, the overall truck transport in the autonomous intercontinental maritime logistic chain involves significantly less truck transportation.

Figure 7 The large-scale intercontinental maritime logistics chain

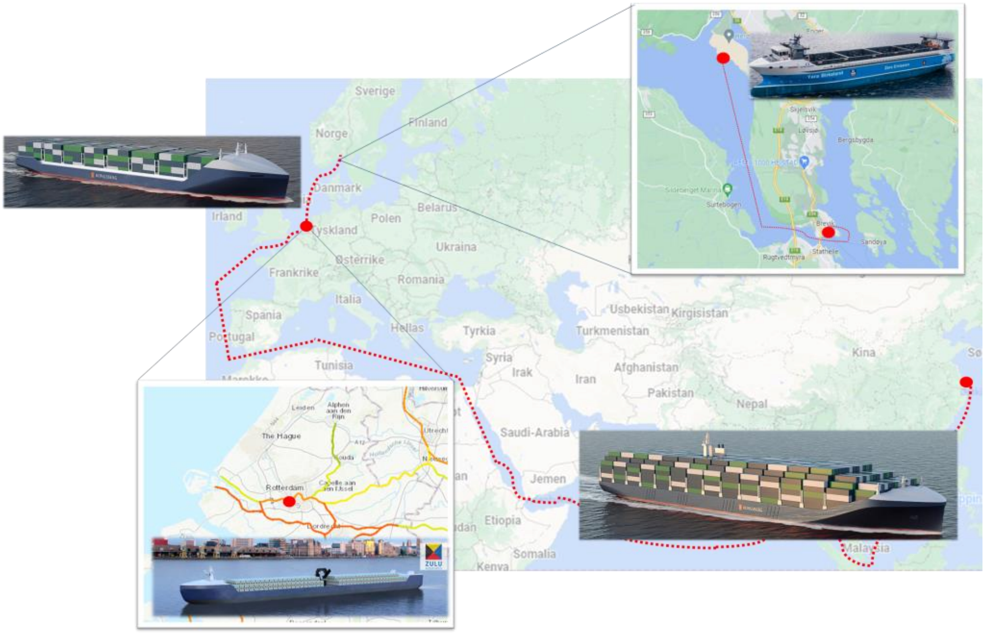

Figure 8 The large-scale intercontinental autonomous maritime logistics chain

To realise the autonomous intercontinental maritime logistic chain, several constraints must be removed. The political environment needs to drive the process of regulatory changes, and provide incentives through policies, the autonomous operation of autonomous ships must be economically viable, societal acceptance must be in place (e.g., by demonstrating societal benefits), the technology must be in place, it must be legal to operate autonomous ships, and they must have a positive impact on the environment.

4.3.2. State of the Art: existing roadmaps

Below we describe roadmaps where autonomous shipping has been the- or one of the focus areas. We then discuss how these are aligned and complementary to the AUTOSHIP roadmap.

The SMASH! Roadmap[2] is a roadmap developed by the Netherlands Forum for Smart Shipping concerning the development of "smart shipping" in general, within which autonomous shipping is one of the elements.

For a series of business cases (deep-sea, shortsea, inland cargo ship, inland ferries and unmanned surface vessel), a vision and key challenges towards 2030 are presented along the line of different development areas comparable to the roadmap components defined for the AUTOSHIP Roadmap. There is less focus on the actual activities needed to reach the overall goal of autonomous shipping but indeed a valuable overview of the key challenges. The key challenges are compatible with the key challenges defined in the AUTOSHIP Roadmap. The overall goals for each shipping segment in the SMASH! Roadmap are presented in Table 1:

Table 1 Overall goals for autonomous shipping in 2030 (from the SMASH Roadmap, 2022)

Sector	Goals for autonomous shipping in 2030
SSS	In 2030, the first generation of partially autonomous ships is operating with a reduced crew which has responsibility for the operation and is supported by shore control centres, who have a comprehensive awareness of the situation on board. Sailing with an unmanned bridge is technically and legally possible outside VTS/restricted areas. Crew is on standby to resume control in the event of anomalies
IWS	Automated inland vessels use artificial intelligence and various sensors on board for large parts of the journey, supplemented with data from waterway authorities and data from other ships. On-board software is able to read the waterway, warn the operators, anticipate changes and resolve traffic situations involving other ships. Most ships have intelligent warning systems that support the crew in sailing smoothly and safely. Part of the inland shipping fleet can sail semi-autonomously, supported by the crew on board or from a shore control centre. Fully autonomous inland vessels (stage 4, no crew on board, no crew in a shore control centre) are not expected in large numbers by 2030.
DSS	Not yet formulated

[2] https://www.smashroadmap.com/

The R&D Roadmap for smart and autonomous sea transport systems (SINTEF Ocean and TCOMS, 2020) is a roadmap developed by the research institutes SINTEF Ocean and the Technology Centre for Offshore and Marine, Singapore (TCOMS) in order to prioritise 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). The roadmap presents the critical areas and elements that are considered as key capabilities to enable the development of smart and autonomous transport systems. 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.

The consortium "One Sea" has created a roadmap with the goal of having the first autonomous maritime system in operation by 2025 (ONE SEA, 2023). The roadmap is divided into main themes: Operational; Technical; Security; Regulatory; Traffic Control and Ethical. Such a multidisciplinary approach, engaging stakeholders along the overall value chain, is something we find critical in our own approach in the AUTOSHIP Roadmap.

The EU Horizon project AEGIS[3] is planned to produce a roadmap for autonomous shipping in Q2 2023. Focus there is more on logistics and terminal operations and plans are made to align the roadmaps in AUTOSHIP and AEGIS where the more ship system centric view of the AUTOSHIP roadmap will complement the logistics and terminal view of the AEGIS roadmap.

The AUTOSHIP Roadmap complements the existing roadmaps by a more thorough and detailed description of the current status of the roadmap components and the more detailed description of which concrete policy actions are needed to overcome the factors constraining the progress towards reaching the overall goal of large-scale adoption of autonomy in intercontinental maritime logistics shipping.

4.4. METHODOLOGY

The roadmap methodology is based on five steps: First, the goal that we want to achieve was defined. Then we limited the scope of the study. We then identified the problems, or constraints, that must be overcome through studying the PESTLE elements and grouped them into main themes. An analysis of commercial initiatives was also conducted to define the current development state, and to serve as a basis for prioritization of the constraint groups and to propose a sequence for when they should be addressed. Finally, we propose a timeline for addressing the constraints.

How are the analysis done?

[3] https://aegis.autonomous-ship.org/

The analysis of the building blocks that are required to realise large scale intercontinental autonomous maritime logistics is based on PESTLE:

- **P – Political:** The political environment that must be in place (reasoning in section 5, constraint identification in section 6)
- **E – Economic:** The economic, or financial, conditions that will stimulate investments in autonomous ships (reasoning in section 5, gaps in section 7)
- **S – Societal:** The societal aspects that either motives for autonomous ships or must be overcome (reasoning in section 5, gaps in section 8)
- **T – Technological:** The technological building blocks that must be in place (section 9)
- **L – Legal:** The legal and regulatory framework that must be in place, for approval of operation, certification of ships and crew (section 10)
- **E – Environmental:** The environmental benefits that motivates for investments in autonomous ships (reasoning in section 5, gaps in section 7)

The studies of each element were done by literature reviews and developments through the AUTOSHIP deliverables including the stakeholder engagements therein. The roadmap was developed based on these studies and by presenting and discussing the roadmap with the AUTOSHIP partners, the AUTOSHIP and AEGIS strategic advisory groups, and by distributing the roadmap draft and a survey to these and to participants in the meeting series *Joint EU Smart Shipping & Logistics Platform meeting*[4]. In total, we received 15 responses to the survey, results given in Appendix A in section 14.

4.5. STRUCTURE OF THE REPORT

The report is structured as follows: The AUTOSHIP roadmap is summarised and presented in section 3. An introduction to the report, including definitions of the autonomous ship and autonomous ships system, as well as the methodology for the work, is given in section 4. Section 5 discusses why autonomous ships are relevant, while sections 6, 7, 8, 9, and 10 discusses the PESTLE elements, the status and the gaps that we have identified. Section 11 discusses the development status by investigating what commercial initiatives are launched within the deep-sea, shortsea, and inland waterways segments, and what the goals in terms of autonomous operations are. Section 12 concludes the study and identifies the main constraints that must be overcome to take the steps towards large-scale intercontinental autonomous maritime logistics.

[4] The meeting series is hosted by NOVIMOVE and includes the projects: NOVIMOVE, PLATINA3, LASTING, IW-net, AUOTSHIP, AEGIS, ENTRANCE, CURRENT DIRECT, BOOSTLOG, Interreg, MOSES, AUTO Barge.

5. WHY AUTONOMOUS SHIPS ARE RELEVANT

There are three main reasons why autonomy in shipping is interesting. Firstly, autonomous ships have potential advantages compared to conventional ships in terms of safety and energy- and cost efficiency. Secondly, autonomy may improve competitiveness of shipping relative to other transportation modes, most importantly road transport (Peeters, et al., 2020). The reason for this is the potential benefits of autonomy, some of which are nicely summarised in (Rødseth Ø. , 2018):

- Reduced exposure to dangerous situations: Work on ships and in cargo handling areas is dangerous and more automation can reduce humans' exposure to dangerous situations.
- Lower damage related costs: There are many mishaps that can be avoided with increased use of automation. Most are minor in terms of health and environment consequence, but still costly to repair.
- Reduced crew cost: This is mostly an issue for smaller ships where crew cost is a large fraction of the operational cost.
- Slow steaming: This is related to lower crew costs where this may be a key to make slow-steaming viable in terms of crew cost and also crew welfare.
- Lower structural costs: Autonomy allows removal of accommodation section and associated costs. This is again most important for smaller ships.
- Better environmental performance: This can be due to no energy used in accommodation, more cargo carrying capacity, lower air drag, etc.
- New ship designs: Removal of accommodation allows new designs more optimised, e.g., for automated cargo operations. Also, the use of many smaller ships falls into this category.

Thirdly, autonomous ships may answer the increasing challenges related to recruitment of skilled crew.

One should note that these benefits are mostly related to the ship unmanned (ISO, 2022). In that case autonomy is only a necessary means to enable the operation of the ship without humans onboard. Even with a fully manned RCC in operation, some degree of autonomy is needed to handle situations when communication links are lost and to make it possible for the RCC operators to supervise several ships.

The above-mentioned benefits can be categorised and reaped along six main themes. These are discussed in more detail below.

5.1. INCREASED COMPETITIVENESS (ENABLE MODAL SHIFT)

Autonomous shipping is not a goal in itself, but increased automation and independence of humans may have significant benefits that makes autonomy in shipping attractive. Perhaps the most important driver for autonomous ships is that autonomy can enable the uncrewed ship. If the crew is moved to land-based jobs, such as RCC operators and port-based crews providing necessary services for the unmanned ship, and the number of crew involved in the operation of each ship is reduced, it is possible to improve the competitiveness of waterborne transportation; both transportation cost and flexibility could be improved. Transportation cost could be reduced because the operational cost related to onboard crew is significant in many market segments. Taking the 75m long AUTOSHIP shortsea demonstrator ship as an example, 7 to 8 crew are always onboard, making crew related operational costs significant. Removing the onboard crew and replacing them with a reduced crew on land, could make it possible to operate more ships with the same number of crew, which would reduce the operational costs for each ship.

Flexibility could be increased because reduced operational costs could enable several smaller ships for the same cost, extended operational hours, and increased freedom in choosing sailing speed (such as slow steaming (Kretschmann & Burmeister, 2017)).

Increasing competitiveness of waterborne transportation is important because truck transportation keeps increasing even though it is the least sustainable form of transportation, causing the highest negative societal impacts, quantified as external costs in (van Essen, et al., 2019). External costs are costs incurred by a third party because of a transaction which the third party is not a part of. External costs are quantified in monetary terms for the most important transportation modes in Europe in (van Essen, et al., 2019). This gives a convenient method of comparing transportation modes and enables trading-off transportation costs and societal costs.

As seen in Figure 9, which is taken from (Molica Colella, et al., 2023 [in print]) and is based on estimates in (van Essen, et al., 2019), waterborne transportation causes considerably less costs for the society than truck transportation.

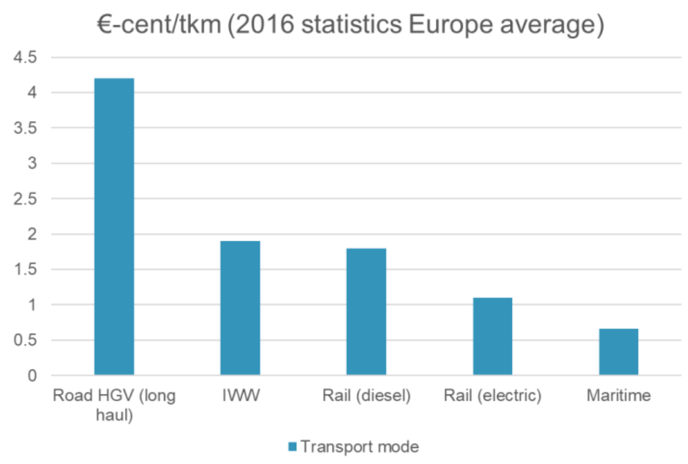

Figure 9 Average external costs in €-cent/tkm for the EU28 countries. Data from (van Essen, et al., 2019), figure from (Molica Colella, et al., 2023 [in print])

In light of efforts to decarbonise road vehicles, including trucks, some might think that moving cargo from road to water is not an important objective anymore. However, if we investigate the average external cost per category, as given in Figure 10, we find that trucks cause significant societal costs in other categories than those related to emissions. This means that even if we compare zero emission trucks to the other transportation modes as they are today, waterborne transportation still causes significantly lower external costs than trucks, see left part of Figure 11. Furthermore, zero-emission solutions for waterborne transportation are also currently intensively researched, such as by the SFI Smart Maritime (SFI Smart Maritime, 2023), and if we look at a future situation where all transportation modes are emission free, we find that waterborne transportation will cause even less external costs compared to truck transportation, see right part of Figure 11.

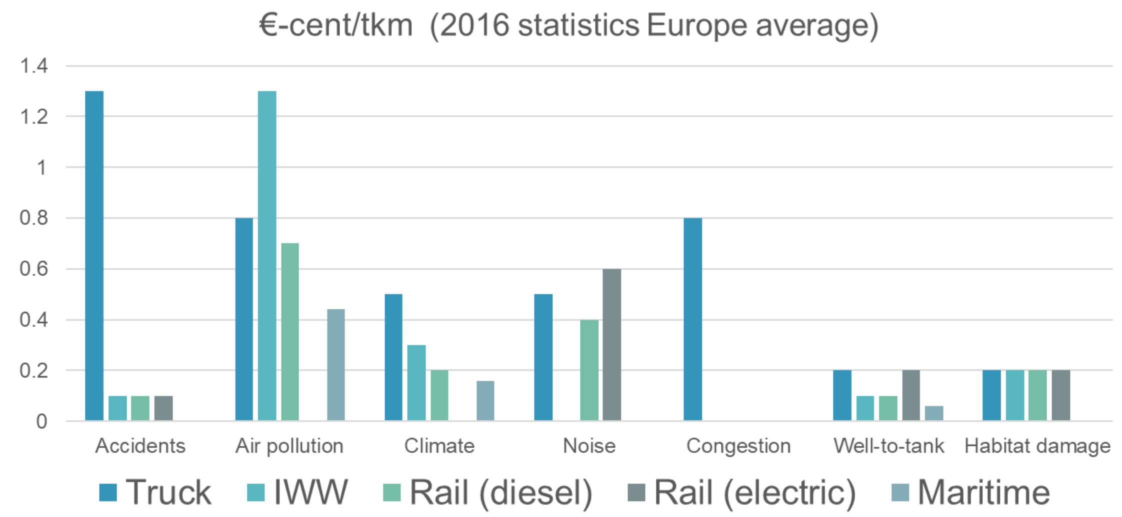

Figure 10 External cost per category in €-cent/tkm for the EU28 countries. Data from (van Essen, et al., 2019), figure from (Molica Colella, et al., 2023 [in print])

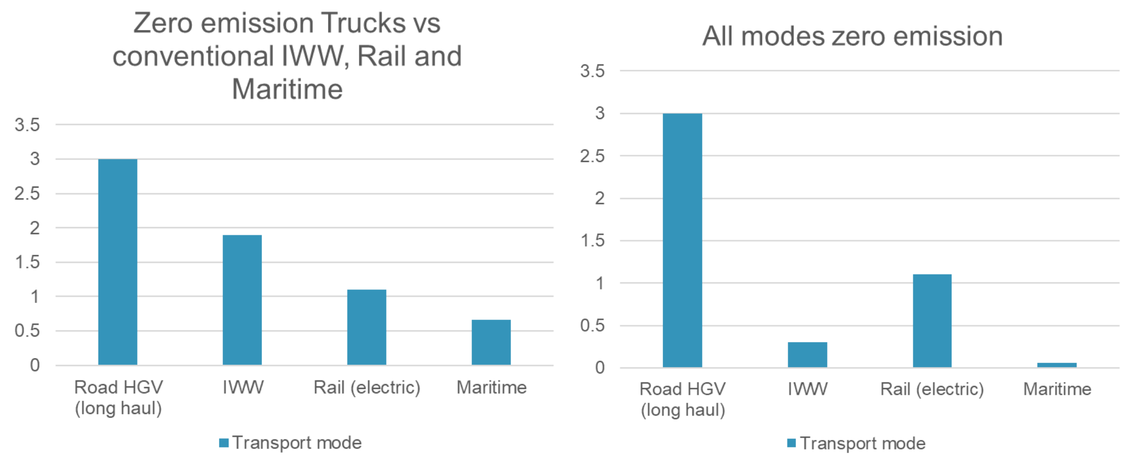

Figure 11 To the left: Zero emission trucks compared to rail and waterborne transportation as they are today. To the right: comparison of all transportation modes zero-emission. Estimates in €-cent/tkm for the EU28 countries. Data from (van Essen, et al., 2019), figure from (Molica Colella, et al., 2023 [in print])

Working for zero-emission solutions for all transportation modes are of course very important, but as we see from the external cost estimates, it is also very important to keep working for shifting cargo from road to sea such that societal costs related to transportation is reduced.

Cost reductions and increased flexibility resulting from autonomy will make waterborne transportation more competitive to trucks and could facilitate the long-standing goal of a modal shift from road to water (European Commission, 2011). This view is also supported by the review on autonomous ships in (Munim, 2019), who argues that MASS can contribute to moving cargo from road to sea, and (Peeters, et al., 2020) who believes that unmanned inland cargo vessels could induce a paradigm shift in the transport sector .

5.2. IMPROVED WORKING CONDITIONS AND MORE INTERESTING JOBS

In addition to increased competitiveness, autonomy may give other benefits related to existing challenges in the job market for shipping.

Firstly, shipping is struggling with recruitment of competent seafarers (Nguyen, Ghaderi, Caesar, & Cahoon, 2014), (SUZUKI, 2021), (de Vos, Hekkenberg, Osiris, & Valdez, 2021), and with seafarer health and safety (Oldenburg, Baur, & Schlaich, 2010). Recruitment is also a challenge in inland waterways (Meersman, et al., 2020), and in some countries the available workforce is becoming a major societal problem, leading to initiatives like MEGURI 2040 (The Nippon Foundation, 2022) which aims for transforming the Japanese fleet to 50% autonomous by 2040 to tackle the lack of workers.

Autonomy may improve working conditions and reduce the risk for crew health and safety, and thus make seafaring jobs more attractive. Autonomy making seafarer jobs more attractive is also discussed in (Tsvetkova & M., 2022). Furthermore, when autonomy is used to enable uncrewed or unmanned ships, new, more attractive land-based jobs are created. The most obvious reason for this is that if seafarers are moved from the ships to land-based jobs, such as operators in RCCs and port-based crews for maintenance and cargo-handling operations, etc., they are no longer in risk of being in harm's way (e.g., if a fire or shipwreck occurs) and they no longer need to be away from home for extended periods. But even for onboard crew there are several operations, such as cargo handling and mooring, which could be automated and as a result remove the crew from hazardous situations, making their jobs safer and more attractive. Furthermore, transferring jobs from sea to shore will result in an improvement in work and rest hours regulations. Currently there are reports addressing the relationship between seafarer's fatigue to these regulations, which worsen the job satisfaction (Baumler, Bikram, & Momoko, 2021).

Secondly, crew logistics is another major challenge for shipping, drastically amplified during the COVID-19 pandemic, where seafarers' well-being was seriously threatened by the inability to change crew on time (Slišković, 2020). Onboard seafarers could not leave the ship when their contract expired, or their rotation period was over, while at home seafarers had to stay home when they should have been at work and thus lost their income. Moving seafarer jobs to RCCs will remove the challenges related to crew change caused by the pandemic as this was caused by quarantine regulations and travel restrictions. It will also reduce the general challenges related to crew logistics as crew no longer need to travel over long distances, sometimes across several countries, to get to and from work. This gives both a more controlled working environment for the workers, and increased resilience for the employer (will be easier to change working schedules).

Thirdly, and finally, moving seafarer jobs to land based remote control centres may attract people from groups that currently are underrepresented. Currently, women represent only about 2% of the global seafarer workforce (ITF Seafarers, 2023). Moving seafarer jobs to land is considered likely to promote gender equality (Tam, Hopcraft, Crichton, & Jones, 2021). It also opens for inclusion of people with special needs as it will be possible to design offices and operator stations with this in mind.

5.3. REDUCING ENVIRONMENTAL IMPACT OF SHIPPING

The roadmap to green shipping, publish by the SFI[5] Smart Maritime[6] (Gamlem, 2022), suggests a four-step approach to decarbonization. Autonomy will be an important contributor to three of these steps. Firstly,

[5] SFI is a centre for research-based innovation and provides an opportunity for long term cooperation between industry companies and research partners: https://www.smartmaritime.no/main/shortcuts/what-is-a-sfi/

[6] SFI Smart Maritime is a Norwegian center for improved energy efficiency and reduced harmful emissions from the maritime sector: https://www.smartmaritime.no/main/shortcuts/about-smart-maritime/

(Gamlem, 2022) proposes the step *Logistics* and the target of the step is to maximise cargo carried relative to energy use. When autonomy is used to enable uncrewed ships, it also reduces the energy needed per transportation work (tkm). This in turn reduces the emissions, and thus, increases carried cargo relative to energy use. The contributing factors are increased cargo capacity, removal of power consuming equipment related to crew, some reduction in wind resistance, and the potential for more energy efficient ship designs. Some also believe that reduced sailing speeds may be possible due to reduced operational costs, which in turn would reduce power consumption for propulsion. This would however need to be traded off against the total performed transportation work, generated revenue, and the need to build more ships with the cost and emission implications that this has. The roadmap in (Gamlem, 2022) finds that some speed reduction gives good results, but that the effect diminishes as the speed becomes lower.

Secondly (Gamlem, 2022) proposes the step *Energy use and efficiency*. Autonomy can enable the uncrewed ship and a ship without humans onboard gives increased freedom for the ship designer to optimise the design for minimal energy usage, without considering facilities and properties that are important to ensure a good working environment for humans. Examples are that all accommodations and crew related equipment can be removed, which gives more freedom in the hull design and in the placement of ship systems and equipment, and that properties such as wave induced motions that would make life onboard difficult for humans are less important. Removal of crew related equipment also gives a direct energy usage reduction (Allal, Mansouri, Youssfi, & Qbadou, 2018) (Kretschmann & Burmeister, 2017).

Thirdly (Gamlem, 2022) proposes the step *Alternative Fuels.* Some of these requires more space for energy storage. As an uncrewed ship will have more available space for cargo, this extra space could also be used for storage of alternative fuels.

Moving cargo from road to water is in itself a means to reduce GHG emissions from transportation. As seen in Figure 12, which is taken from (Gamlem, 2022), CO2 emissions from most shortsea transportation of cargo causes considerably less emissions than road transportation. As discussed in section 5.1 autonomy will contribute to making waterborne transportation more competitive, and thus, to shifting transportation from road to water.

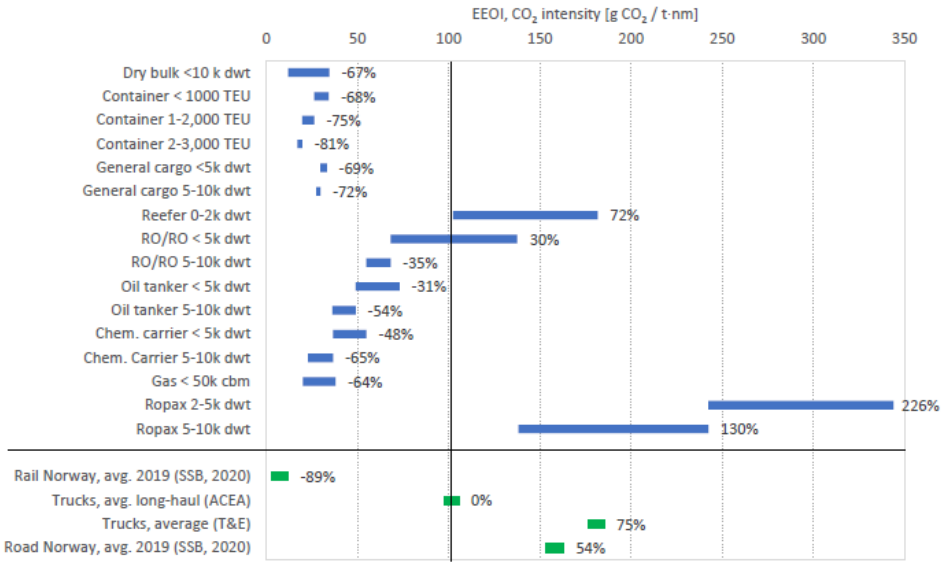

Figure 12 Comparison of carbon intensity (EEOI) of a number of shortsea vessels to land-based transport. The figure is taken from (Gamlem, 2022)

5.4. SAFETY

Improved safety is a widely debated potential significant benefit of autonomous ships. Many authors argue that as most accidents can be traced back to human errors, autonomy will improve safety by removing the root cause for such accidents. Others point out that this argument is too simplistic because humans also prevent an unknown number of accidents, because humans will still be involved for the foreseeable future (either onboard or in an RCC), and because the degree to which autonomy is able to avoid accidents depends on the individual autonomous ship system design and performance. According to (de Vos, Hekkenberg, Osiris, & Valdez, 2021) increased safety is one of the primary drivers for autonomous shipping, however, this improvement in safety is yet to be quantified in academic literature. Still, (de Vos, Hekkenberg, Osiris, & Valdez, 2021) finds through a statistical analysis that even if autonomy should prove to not reduce the number of accidents, autonomy will still improve safety at sea because less humans will be involved in the accidents. This view is supported by (Tsvetkova & Hellstrøm, 2022), who also argue for increased safety due to autonomy providing constant and advanced situational awareness, and to decreased fatigue of the crew.

Another point of view is that even though humans will not be totally out of the loop, they are expected to be in a less stressful and less fatigued condition and perform better in terms of avoiding accidents. I.e., the operator will be in better condition and have access to better decision support to avoid accidents.

Although the safety impact remains to be quantified, it seems apparent that autonomous ships will bring a positive impact on safety.

5.5. LESSER NEED FOR SPACIOUS TERMINAL OPERATIONS

Finally, areas close to the shoreline are now seen as among the most valuable, especially in urban areas (Rødseth, Nesheim, Holte, & Rialland, In print - 2023). Public demand for moving ports and terminals from city centres is ever increasing. This will increase last-mile truck transport as cargo now will be landed farther from the city. Autonomy may make it possible to use several smaller ships rather than the large ships used today. By automating cargo handling, e.g., in combination with RORO solutions as in ASKO (Kongsberg, 2020), very little land-based infrastructure will be required. If this is combined with just in time arrival and departure of cargo, one can set up waterborne transport solutions directly into city centres or to small rural quays with minimal requirements on terminal infrastructure. This could emerge as an attractive alternative to truck transport. The introduction of autonomous ships may also have an impact on more conventional port operations. As the demand for intermodal connections is expected to increase, including smaller autonomous ships and barges for hinterland and last mile transport, cargo can be expected to spend less time at the terminal and thus reduce the need for terminal storage area.

5.6. GLOBAL TRANSPORT AND ECONOMY

Incidents from the last few years, such as the "Ever Given" accident, the COVID-19 related societal shutdowns in e.g., China, gave immense consequences for the global economy. Global warming is another global event with potentially significant impacts on global supply chains. One example is the draughts experienced in Europe in 2022, rendering vast stretches of inland waterways inaccessible for larger ships.

Autonomous unmanned ships could increase the flexibility and resilience in transport systems and reduce the consequences of single incidents. Especially if smaller ships become economically viable and replaces larger ships. The breakdown of a smaller ship will have a smaller impact as it is less likely to obstruct important infrastructure like canals, and since its unavailability will constitute a smaller reduction in capacity. Smaller ships can also operate under lower water conditions caused by droughts than larger ships.

The role of transportation in spreading virus is discussed in (Rodrigue, Luke, & Osterholm, 2020) and transportation is found to be an important factor for spreading virus around the world. Which is why we saw such huge drops in all transportation modes during COVID-19 (Sawers, 2020). To overcome the challenges imposed by events such as the COVID-19 pandemic, it is necessary to automate a larger part of the supply chain, on land and water, to reduce the spread potential and avoid the shutdown of operations. Autonomy as a means to fight the spread of COVID -19 is discussed in (Kapser, Abdelrahman, & Bernecker, 2021).

Autonomous ships will hence be an important piece of the puzzle to solve the vulnerability of the global supply chains.

6. GAP IDENTIFICATION: FUNDED R&D AND PROJECTS, THE POLICY ENVIRONMENT

As elaborated in section 5, the benefits of MASS are clear, also in terms of societal and environmental benefits. This should be a strong motivation for policy makers to prioritise MASS in policies and R&D funding. So, what is the status on policies, R&D, and project funding?

6.1. EXISTING POLICIES

In (Fonseca, Lagdami, & Schröder-Hinrichs, 2021) it is pointed out that autonomous ships will not take over the market overnight, and that the adoption will be defined by the policy environment. They note that the market for autonomous ships is limited, and that a proper set of policy actions are needed. That is, accelerating a shift towards autonomous green shipping can be done by incentivizing shipowners by prioritizing autonomous ships in policy agendas.

There are several policy instruments that can be used to influence decision makers (Takman & Gonzalez-Aregall, 2021): economic (e.g., taxes and subsidies), administrative (e.g., legislations, technical requirements, environmental classifications) and informative (e.g., eco-labelling, advising, education, training, research, and development).

Economic incentives could be in the form of direct grants intended to reduce investment risk. It is however important to avoid unfair distortion of competition, and to form such policies in a way that there is a clear connection between the grant and the benefit that the policymaker receives in return. One way of achieving that is to form the policy in such a way that the grant is given for the quantified benefit that the investment will result in (e.g., internalising the externalities). An example of such a policy is ENOVA (Enova, 2022) which has given grants to several autonomous ship projects by internalising the external cost of GHG emissions, and granting subsidies proportional to the cuts in existing GHG emissions that the projects will result in. This is already becoming a significant driver for Norwegian cargo owners to invest in new, zero-emission, highly automated or autonomous ships. With the further consequence in accelerated technological developments within several technology providing companies. The ENOVA program does not specifically target autonomous ship investments, and it should be noted that the autonomous ship projects supported by ENOVA are mainly given grants due to the use of batteries. Nevertheless, it is an example of a successful policy formed to stimulate investments in line with political goals. It is also an example of how policies targeting specific societal benefits stimulates technological development.

Policies like ENOVA could be adopted by other countries to further accelerate the green shift, and to contribute to the further uptake of autonomy in shipping. However, there are a range of investments needed to accelerate autonomous shipping towards large scale intercontinental shipping that might fall outside the reach of such policies.

Autonomous ships will depend on infrastructure adapted for autonomous ships, like mooring, cargo handling, supply and energy replenishment, connectivity, RCCs, etc. This infrastructure will be expensive and the study in (Fonseca, Lagdami, & Schröder-Hinrichs, 2021) points to this dependency as a barrier for the uptake of autonomy and suggests more studies on what policy options would be required to make the required infrastructure available and in what form. Interestingly, this infrastructure could be shared by several ships owned by different ship owners to bring down the cost experienced by each ship to a competitive level, as shown for the RCC cost by (Ghaderi, 2019). Competitors sharing infrastructure for autonomous ships could perhaps best be realised through a new business model where the infrastructure is offered as a paid service to autonomous ships. But to get such a business model going, initial investments are needed, and new policies could be developed to stimulate these.

An alternative to internalising externalities through offering grants to investors that reduce external costs could be to enforce policies such as requiring that commercial parties pay for the societal costs that they cause. Some such policies already exist in some areas, such as CO2 taxes and road taxes. It is possible that such taxation could contribute to accelerated uptake of autonomy in shipping as autonomy used to enable unmanned ships, results in reduced emissions and costs.

Administrative policies like legislations and technical requirements could also stimulate the uptake of autonomy in shipping. While the legal framework and regulatory aspects required to allow autonomous shipping are discussed in section 10, regulations could also be used to stimulate uptake of autonomy. As an example, upper limits to the emission of NOx have resulted in a large-scale uptake of scrubbers onboard existing maritime ships. Similarly, legislations or technical requirements could be enforced to stimulate uptake of autonomy, e.g., by regulating tasks known to have high risk for human or asset safety by enforcing automated solutions, or limits to where manual labour can be used. Examples could be that mooring by manual labour could be prohibited to ensure worker safety, or that no humans can be within a certain distance during lifting operations, or even prohibit humans from being in cargo hulls during cargo handling operations. Another example could be to require that all ships communicate certain data (e.g., intended route) to facilitate safe interactions between autonomous ships and between autonomous and conventional ships.

Enforcing such changes through legislations or technical requirements will require that technical solutions are readily available. It would also have to be done over a period giving the industry sufficient time to adapt, without causing unacceptable costs that could potentially reduce the competitiveness of shipping. One option could therefore be to set a date at which point ships would have to comply with the new regulations or requirements. This has also been done previously, such as for the NOx emission requirements.

Informative policies could influence the public acceptance of autonomous ships. Public acceptance is important in many levels, ranging from consumers preferring certain services over others, to investors being confident in new technology. Education, research and development, and associated dissemination in both scientific and non-scientific channels, can play an important role in this. Eco-labelling and advertising can also play a role.

6.2. FUNDED R&D AND INNOVATIONS

The AUTOSHIP partner PNO did an analysis of funded R&D and innovations in deliverable D9.6, which is confidential. This section presents some of the results related to funded R&D and innovation projects and discusses the implications on policies. Notice that the citations (approved for sharing by PNO) from D9.6 are marked in italics, and that the figures in this section are also taken from D9.6.

More insights about the key players currently shaping the innovation scenario, research and development (R&D) projects, other initiatives, and their objectives and trends can be found (Molica Colella, et al., 2023 [in print]) which is also based on some of the work in D9.6**.**

The analysis groups the funded projects into four main areas:

- ***Projects addressing transport and logistics****: these projects are pioneers. The results include AEGIS and MOSES, with which contacts have been established already in WP6 to set up common workshops and activities*
- ***Projects addressing logistics****: these projects address e-infrastructure and automation in ports. They are not related to autonomy but may be interested in the requirements that autonomy can bring along with the development of Vessel-to-Shore interfaces.*
- ***Projects addressing transport****: these projects include a large set of autonomous vessels related initiatives (in the picture only projects with a focus on IWW and SSS have been retained).*
- ***Cross-cutting topics (exotics)****: these projects address general thematic related to autonomy of vehicles and may be an opportunity to cross-sectoral interchange.*

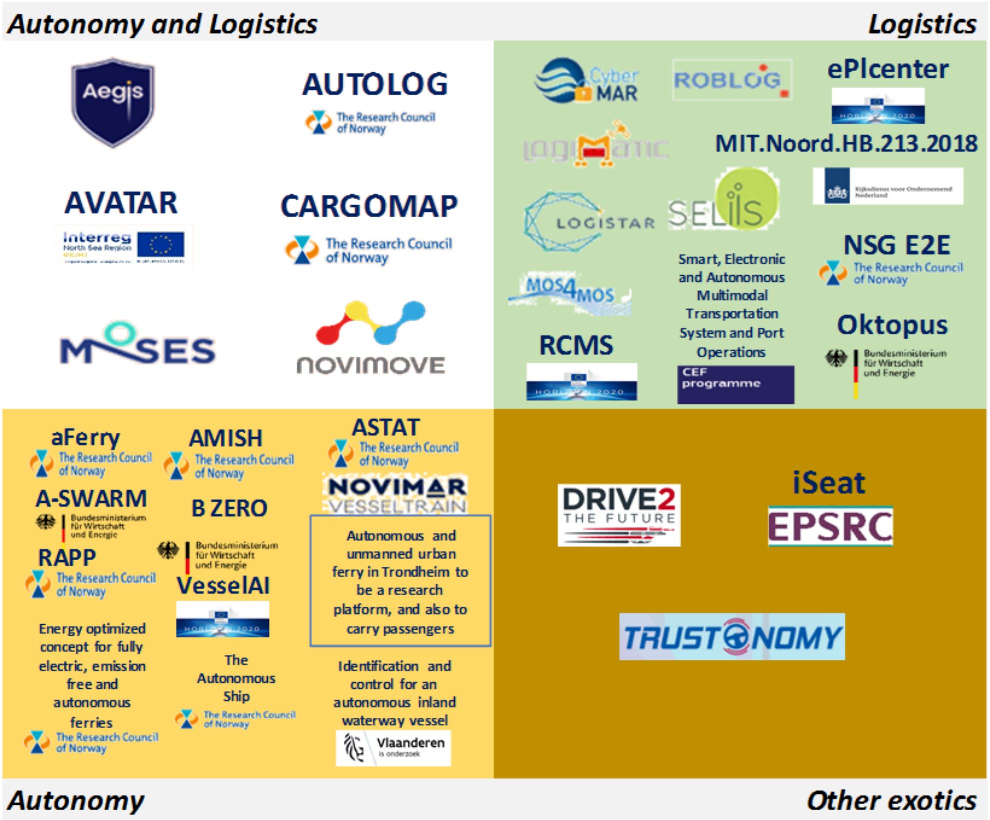

Figure 13 Funded projects mapped int main topics (from D9.6)

The corresponding total received funding has been identified both according to the start date of the projects and to the funding programme. The figures [Figure 14 and Figure 15] *show that **2020 is the year with more funded projects selected (21)** and with more funding received (about € 61.9 million), followed by **2016 with 8 funded projects selected** per a total of funding received of about € 40.3 million.*

*Regarding to the funding programme/grantor body, **RCN (Norway)** is the one with more selected projects (38) followed by **H2020's RIA** with 13 projects. RIA is also the scheme with more funding received (€ 93.4 million) followed by RCN (Norway) with € 37.7 million. This is connected to the maturity stage of the technology.*

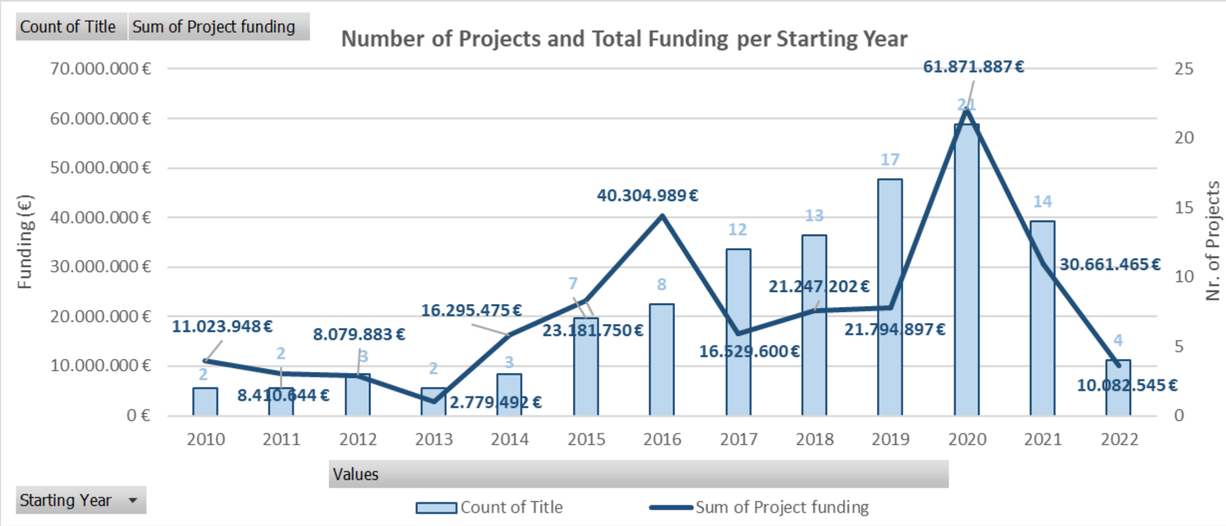

Figure 14 - Number of Projects and Total Funding per Year (from D9.6)

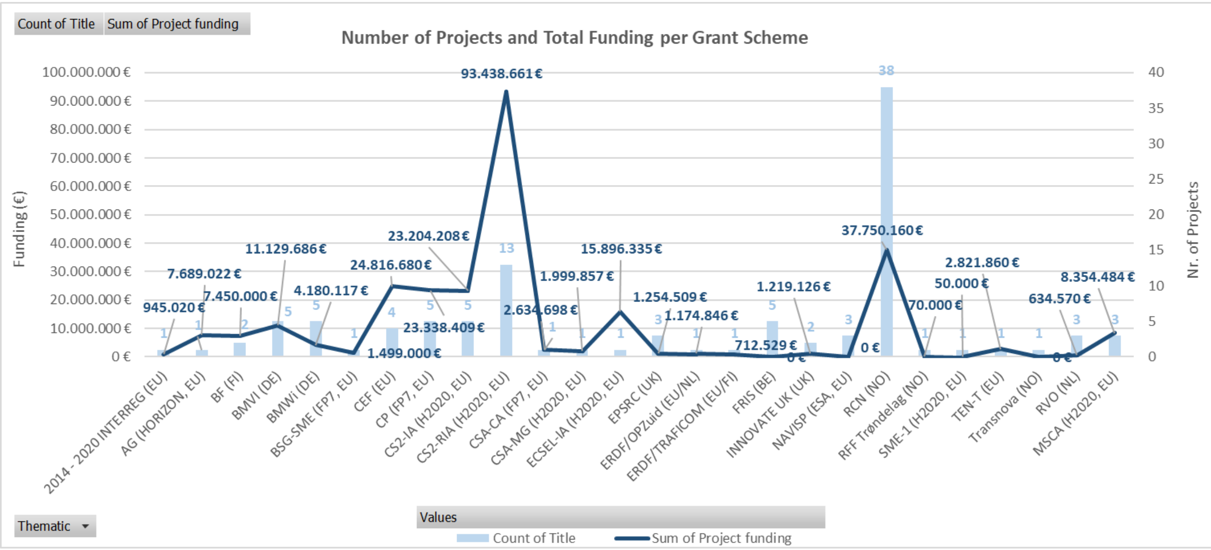

Figure 15 - Number of Projects and Total Funding per Grant Scheme (from D9.6)

The analysis of funded projects concludes with the following key takeaways:

- *Most of the selected projects deal with Maritime Transport with a balance between passenger and goods, while a smaller set of projects deals with automated logistics and e-infrastructure.*
- *It is hard to find projects where autonomy is coupled with automated logistics. These are last generation projects and more will be needed to make autonomous shipping a business case for logistic operators (involving the last mile)*
- *When it comes to maritime transport, the IWW and SSS are the most visible segments but not often coupled*

- *There is a lot of smaller "cross-cutting" projects dealing in particular with Autonomy KETs (mostly national) without a specific focus on a maritime market segment and vessel type.*
- *E-infrastructure, fleet-management and monitoring are instead well represented up to CEF projects (infrastructure development)*
- *Vessel-to-shore technologies (dedicated to autonomy) are not explicitly developed in every autonomous ship projects. It is however hard to separate this branch from e-infrastructures.*

In addition to these conclusions, it is worth noting that projects developing infrastructure and supporting services for autonomous ships are under-represented, however, as will be elaborated in section 7, this will be key to enable the uptake of autonomy, thus, it will be important to provide the necessary funding. Moreover, the 489 stakeholders participating in the funded projects have been identified and associated with a role in the maritime transport and logistics value chain, see Figure 16. Most of them are technology providers and developers (231 organisations) testifying to the importance of research and development of the KETs at this stage. On the other hand, infrastructure service providers are the second to least represented stakeholder, which means there is a need to stimulate them to participate in more projects. Possibly through targeted policies or calls for research and development projects.

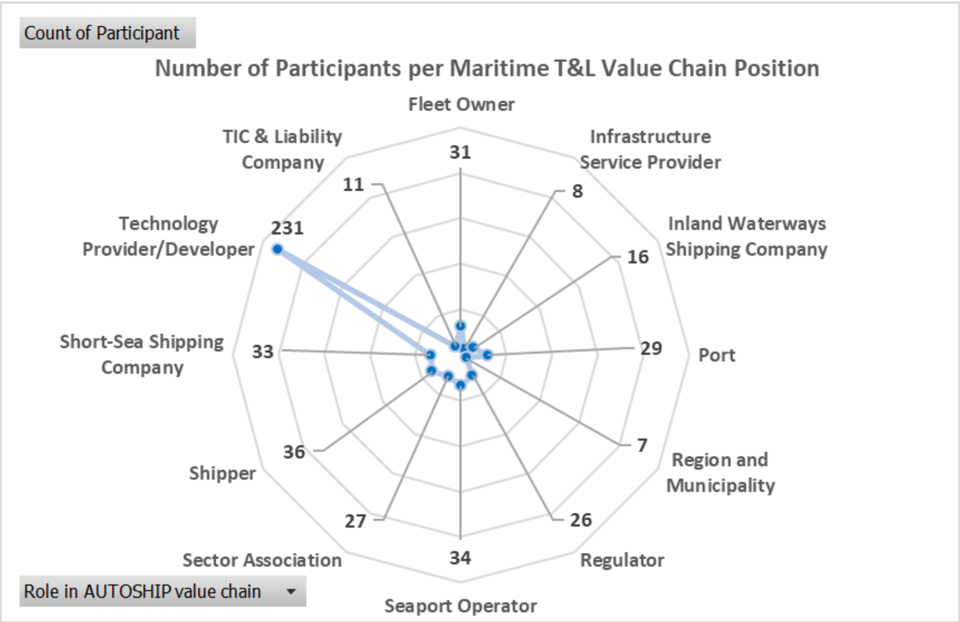

Figure 16 Stakeholders per maritime transport and logistics (T&L) value chain position

We would also like to highlight the analysis finding that RIA is the project form mostly funded, which is natural in the early phase of new technology. Though we are still in a phase where more RIA projects are needed, e.g., as elaborated in the section 9.7, we also believe that a transition towards more IA projects will be needed in the future.

6.3. POLICY STRATEGY

In a lecture by ENOVA (Leistad, 2023), their funding strategy for influencing the development and market uptake of new technology was presented. This is illustrated in Figure 17. Firstly, the new technology must be prioritised in the policy. Then R&D financing is provided, and in turn, innovation financing. The policies initially target lower TRL projects, and gradually moves to higher TRL projects, via technology demonstrators, and investments in full scale technology projects. At a certain point, when the market is ready, the policy focus shifts to infrastructure funding, and taxation and regulation schemes. As the market increases, funding schemes are relaxed (though there will be residual specific technological challenges that needs funding to be solved).

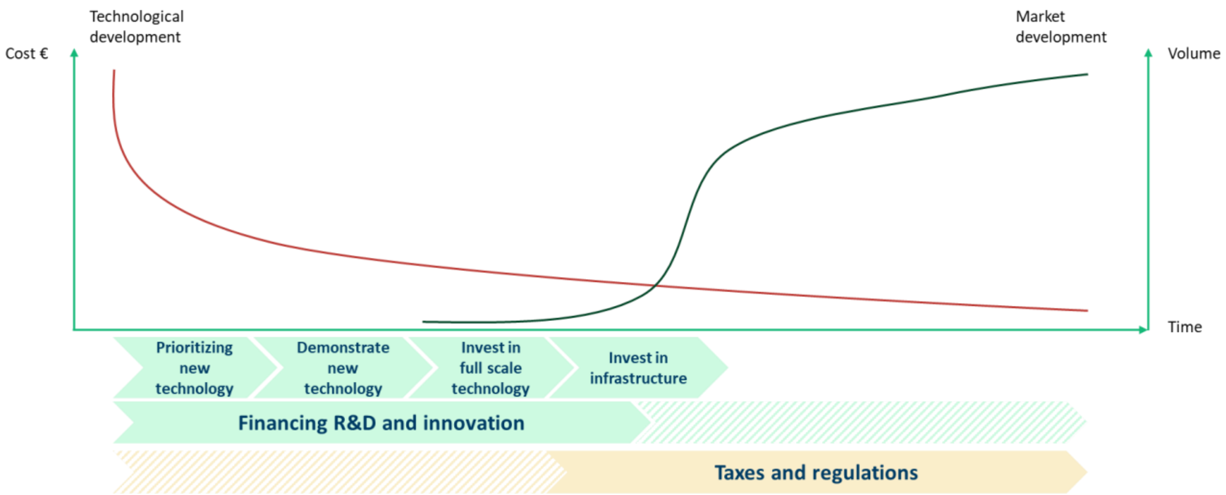

Figure 17 Illustration of the policy strategy for stimulating development and uptake of new technology, as presented by ENOVA (Leistad, 2023)

ENOVA has deployed this strategy to a range of technologies, where the electrification of ships, and cars are probably most relevant for our discussion. This has been a success particularly for ferries and cars. The status for ferries in Norway is that about 22,4% of the 230 ferry connections are electrified (tilnull (Towards Zero), 2023), and more are on the way. The status for electric cars is that in 2022 79.2% of the sold cars were electric, and that more than 20% of the registered cars in Norway were electric (Norwegian EV Association, 2023).

6.4. SUMMARY

In our view, policy actions will be critical to accelerate the uptake of autonomy in intercontinental maritime logistics. This view is supported by the previous success of policy programs like ENOVA. For such programs to be successful, it is important to devise a strategy where several policy actions are deployed in various phases of the technology and market developments. The following gaps were identified:

- International (e.g., EU) policies that internalise external costs by funding investments that reduce societal costs, such as the ENOVA program, are needed to stimulate the investments in new green and autonomous technology-based ships.
- There is a need for initial investments in infrastructure, such as RCCs and required port infrastructure, to accelerate the developments to a level where autonomous ship operations are self-sustainable. However, infrastructure investments will first pay-off when a sufficient user-base is in place, while the user-base cannot grow without the infrastructure in place. International (e.g., EU) policies to provide grants to such investments are therefore needed to stimulate these investments in the initial phase.
- New technological solutions related to infrastructure services are needed to support autonomous ships. These must be researched and developed, before they can be invested in and built. Policy actions to attract infrastructure service providers to participate in research and development and innovation projects are needed. Possibly through calls targeting these stakeholders.
- International (e.g., EU) policies that internalise external costs through fees or taxation schemes, on an international level (e.g., EU policy) are needed.
- New international (e.g., EU) regulations or technical requirements intended to stimulate the transition to autonomous solutions, within a given timeframe, may also be needed to accelerate uptake of autonomy.

We also recommend that policy programs for funding R&D continues, as they are still needed. Depending on the maturity of each R&D topic and technology, a transition from RIA to IA will at some point be needed.

7. GAP IDENTIFICATION: ECONOMY, EMISSION, AND THE BUSINESS CASE

The benefits of autonomous ships are elaborated in section 5, where the main findings are that autonomous ships will reduce costs and emissions, and thereby improve competitiveness of waterborne transportation. Further benefits related to reduced societal costs were also identified, however, the business case was not discussed.

7.1. BUSINESS MODELS

The review in (Munim, 2019) argues that autonomous ships are a possible contributor to moving cargo from road to sea. The review also points out that the new technology ship autonomy is seen by some as a challenger in a market led by huge companies which bases their business models on fossil fuels (Munim, 2019). This makes competition in this market tough and requires a good business model. Though autonomous ships, in our view, are likely to also compete with smaller companies (such as e.g. truckers), the need for new business models to enable autonomous ship uptake identified by (Munim, 2019) is a view we, amongst other authors like (Fonseca, Lagdami, & Schröder-Hinrichs, 2021), share. Furthermore, this lack of business models is identified as a barrier to the adoption of autonomous ships in (Fonseca, Lagdami, & Schröder-Hinrichs, 2021). While both (Munim, 2019) and (Ghaderi, 2019) provides some proposals for new business models, these remain to be studied in more detail and to be proven.

New infrastructure in ports will be needed to support autonomous ships, but if each autonomous ship operator would have to invest in this infrastructure and own it, it would most likely break the business case. However, this infrastructure can be shared by competitors, which is related to the cooperation forms between shipping lines that are identified as an area in need of more research in (Munim, 2019), exemplified by the prediction of stakeholders being more connected and needing to share information in (Rajapakse & Emad, 2019). Vessel sharing as a service is proposed as a business model in (Munim, 2019), and ship management as a service is proposed as a business model in (Ghaderi, 2019), which are other examples of cooperation forms. Strategies and tools for improved coordination between the supply chain stakeholders, and information sharing, is identified as an area needing more research in (Bălan, 2018).

Though the future business models, for autonomous ships and for providing services to autonomous ships, are still unclear, the significant range of benefits elaborated in section 5 is a strong indication that they can be found. One interesting aspect is that several of the services needed by autonomous ships will likely require that they are shared by many autonomous ships to be profitable. This creates an interdependency, and a barrier, that is potentially difficult to overcome; autonomous ships depend on these services, but the services depend on many autonomous ships to be profitable. The challenge will be to get the ball rolling. Who will make the first investments knowing that they depend on other investments to be successful?

7.2. QUANTIFICATION: ECONOMY AND EMISSIONS

The lack of established business models for autonomous ships may be a natural consequence of the knowledge gap in terms of cost and emissions impact identified by several authors. In (Fonseca, Lagdami, & Schröder-Hinrichs, 2021) it is pointed out that technological development is mainly driven by technology vendors, and not by the customers (shipowners and operators) demands. Meanwhile, proven commercial feasibility is key to convince prospective buyers: "*Importantly, technological innovation needs to fulfil customer needs rather than be driven by purely myopic technological ambitions (Christensen and Bower 1996).*" (Fonseca, Lagdami, & Schröder-Hinrichs, 2021). Such proof is missing, in the autonomous ship review (Bălan, 2018) it is pointed out that the reviewed articles do not provide sufficient information to prove that the new technology will outperform existing technology, and that literature quantifying impact is scarce.

In fact, most of the autonomous ship review papers we have investigated find that the application of autonomous ships must be studied in more detail as cost and impact on emissions, in quantitative terms, is unclear due to few available studies (Ghaderi, 2019), (Munim, 2019), (Bălan, 2018), (Gu, Goez, Guajardo, & Wallace, 2020), (Ziajka-Poznańska & Montewka, 2021) and (Fonseca, Lagdami, & Schröder-Hinrichs, 2021). Furthermore, shortcomings in the available financial estimates are identified by (Ziajka-Poznańska & Montewka, 2021). This knowledge gap can be considered a barrier for autonomous ship uptake as it implies high investment risk and discourages potential investors. In (Gu, Goez, Guajardo, & Wallace, 2020) it is suggested that such research may influence the expansion of autonomous ships in transport and logistics. Furthermore, (Tsvetkova & Hellstrøm, 2022) points out that studies of specific shipping segments, or how value creation through autonomous ships differs for different levels of autonomy and onboard manning, are needed.

To advance the state of art for autonomous ship business cases, market, and business models, one must first do more case studies to quantify the impact on cost and emissions. The central questions are:

- How is transportation cost influenced by autonomy?
- How will autonomy impact emissions, and what mechanism is most important (increased cargo capacity, removal of equipment related to the crew, and which consumes energy, reduced wind resistance, reduced weight, etc.)?
- How do these factors relate to market segment?

And possibly the most important question to answer is:

In which applications will autonomy give the most benefits, i.e., which applications should be prioritised for initial development, investment, and public funding?

7.3. IMPROVING THE ECONOMY OF AUTONOMOUS SHIPS

So, what do we know of the economy of autonomous ships? Firstly, there is a general perception that the construction cost will be slightly higher than for conventional ships of the same type and size. Secondly, it is expected that the reduction in crew-related costs will outweigh the additional costs, at least for ships with a certain crew size. Thirdly, the construction and approval of an autonomous ship will initially come at a higher cost than when the technology is matured. This relates to technology cost being higher in an early phase, that it remains to find the most cost-efficient safety design (e.g., level of redundancy), and, perhaps most importantly, the lack of standards for both the technology and for the approval process.

To ensure autonomous ship cost-efficiency, it is therefore necessary to develop standards for the technology (the equipment), for the safe design of the autonomous ship system, and for testing and approval.

Autonomous ships will have lower emissions than conventional ships because they will be more energy efficient. Ships in general also have lower external costs. However, currently, there is no economic incentive rewarding transportation alternatives with lower external costs. As discussed in section 6 and 7, internalising external costs will improve the economy for autonomous ships compared to competing transportation modes. Furthermore, to accelerate uptake in an early phase, funding of early movers, and of building required infrastructure, is likely needed. This is because acquisition costs are relatively high due to the lack of standards and to the technology being in an early phase, and to the autonomous ship market being underdeveloped.

7.4. SUMMARY

The uptake of autonomy in intercontinental maritime logistics depends on new and viable business models. A prerequisite to build such new business models is to understand the cost and emission implications of autonomous ships. Autonomous ships are expected to depend on new services and infrastructure, which implies that there is a potential for new business models designed to supply these services. However, establishing a business to provide such services requires a market (i.e., autonomous ships to buy the services), and it is expected that the services will need to be shared by several ships to bring the costs down to a competitive level. Sharing services implies a certain level of standardisation, such that all autonomous ships are interoperable with the services. The following gaps were identified:

- Lack of knowledge about when and where autonomous ships are applicable, and how the cost and emissions can be quantified.
- Lack of infrastructure and port services for autonomous ships, and this is too expensive to finance for the ship-owner.

- Missing business models for owning and operating autonomous ships (traditional ship owners? Cargo owners become ship owners? Technology provider owns ship and offers transport as a service?)
- Missing business models for providing services to autonomous ships, such as based on sharing resources like RCCs, infrastructure, and maintenance teams, etc.
- Initially, business models are likely dependent on financial support to be economically sustainable. E.g., autonomous ship service providers will have a very limited market, but the market cannot grow if the services are not available.
- No standards for the technology, the autonomous ship system, and the approval process makes the approval process costly.
- Externalities are not internalised.
- Need funding schemes targeting early movers and the establishment of infrastructure and services supporting autonomous ships.

8. GAP IDENTIFICATION: SOCIETAL

The societal benefits are elaborated in section 5, but in short, autonomous ships have the potential to improve competitiveness and thereby contribute to a shift of transport from roads to water, and thus reduce societal costs related to transportation. Furthermore, several countries, and shipping segments, are facing a major challenge related to recruitment. The reasons are that jobs are not considered attractive enough, and that the overall available work-able population compared to demand for workers is reducing. Autonomous ships, or in general autonomy, can reduce this problem by automating tasks previously performed by humans. New, more attractive jobs will also appear; however, these require new education and classification schemes (education and certification is discussed in more detail in section 10.5). Finally, autonomous ships will remove people from harm's way, as discussed in section 5.2.

On the other hand, strong trade unions are concerned with ensuring the interest of workers, which in some cases conflict with automating work-tasks. Autonomy and automation may, by some, be viewed as a threat to jobs, and as such, social acceptance will require public dissemination of societal benefits outweighing potential drawbacks. Furthermore, trust in the new technology must be established such that the perceived risk for potential investors and customers of autonomous ship services is acceptable and outweighed by benefits. Trust is also essential for the human operators that will still be involved in autonomous ship operations such that they can do their jobs efficiently, confidently, and successfully (Mallam, Salman, & Amit, 2020).

Global warming warrants immediate actions to reduce emissions. For transportation, this means using less energy to perform the same work, and to move towards zero emission energy. As elaborated in section 5.3, autonomous ships can play a key role in reducing emissions. However, this warrants a large-scale uptake of autonomy in intercontinental shipping. Which, as discussed in section 6, depends on policy actions such as internalising externalities.

8.1. THE MARITIME STAKEHOLDER VIEW ON AUTONOMY IN SHIPPING

The AUTOSHIP project did a survey on the maritime stakeholder perspective (Rentifi, et al., 2021). The study was also published in (Theotokatos, Dantas, Polychronidi, Rentifi, & Colella, 2022) and included the stakeholders: owners, operators, builders, designers, technology providers, port authorities, regulators, flag states, technical advisors, legal advisors, environmentalists, international organisations, professional societies, academia, research institutions, seafarers and the public.

The main findings in (Theotokatos, Dantas, Polychronidi, Rentifi, & Colella, 2022) are:

- *The transition to autonomous shipping […] is considered beneficial by most of the survey participants.*

- *The participants were inclined towards the effect of autonomous shipping on the jobs number reduction […], but it seems that the complete supply chain as well as the transitional period to develop autonomous shipping was overlooked.*
- *The Seafarers' group seemed to oppose on the concept of the autonomous shipping, whilst the designers/builders/technology providers exhibited neutrality […].*
- *The owners/operators group mostly agrees that the transition to autonomous shipping will assist in the deficit of the seafarers […].*
- *There is an overall consensus that the modification of the training framework […] is essential for the operation of autonomous ships.*
- *The viability of autonomous shipping […] is considered positive for the short-sea, inland and ocean-going ships; neutral for the work ships/boats, whereas it is considered negative for the cruise ships*.

This indicates that several stakeholder groups still need to be convinced that autonomous ships bring benefits outweighing costs (including social costs), and that in general, all benefits are not clear to all stakeholders. It seems that there is a fear of losing jobs, while owners and operators agrees that autonomous ships will play a role in counteracting recruitment issues. It also indicates that the stakeholders believe that autonomous ships are viable in the segments forming large scale intercontinental maritime logistics.

8.2. SUMMARY

Societal acceptance is important for several reasons, perhaps, most importantly, as it has an impact on decision makers wanting to make their product or services more attractive, and because policies are formed to promote the societies needs and will. The main identified gaps in terms of societal acceptance are:

- Dissemination of societal benefits such that the public (and wider stakeholder) acceptance is ensured.
- Make agreements with unions ensuring the future of workers while autonomous ship operations are ensured, also in terms of economy.
- Make the public aware of recruitment challenges, and the future deficit of the workforce.
- Educate stakeholders, such as investors, customers, and operators, and establish trust.
- External costs (costs endured by the society) are mostly not compensated by the party causing them.

9. GAP IDENTIFICATION: TECHNOLOGY

In this section we describe Key Enabling Technologies (KETs) for autonomous ship operations, hereunder a description, status, and the path towards commercial availability (TRL 9). The high-level main components of an autonomous ship system are illustrated in Figure 18. The KETs discussed in this section (and the components of Figure 18 that they include) are:

- Situational Awareness, which includes *Sense and Analyze Environment*.
- Autonomous Navigation System, which includes *Digital Master, Digital Navigator,* and *Manoeuvre Vessel*.
- Intelligent Machinery System, which includes *Digital Chief and Sense and Analyze Equipment*.
- Connectivity and Cybersecurity, which includes *Vessel to shore Communication* (and in the future *Vessel-vessel communication)*.
- RCC, which includes *Fleet Monitoring and Control*.

The discussion on the above KETs in this section will be based on technology developments within the AUTOSHIP project. In addition, this section will discuss auto-mooring, cargo handling and maintenance of unmanned ships, which is not addressed in detail within the AUTOSHIP project. The discussions on these issues are partly based on the feasibility study on autonomous shortsea container shipping, and break-bulk deep-sea shipping, performed by the SFI Autoship (Mørkrid, Bellingmo, & Wille, 2023), and the auto-mooring gap analysis of the SFI Autoship (Bellingmo & Jørgensen, 2022).

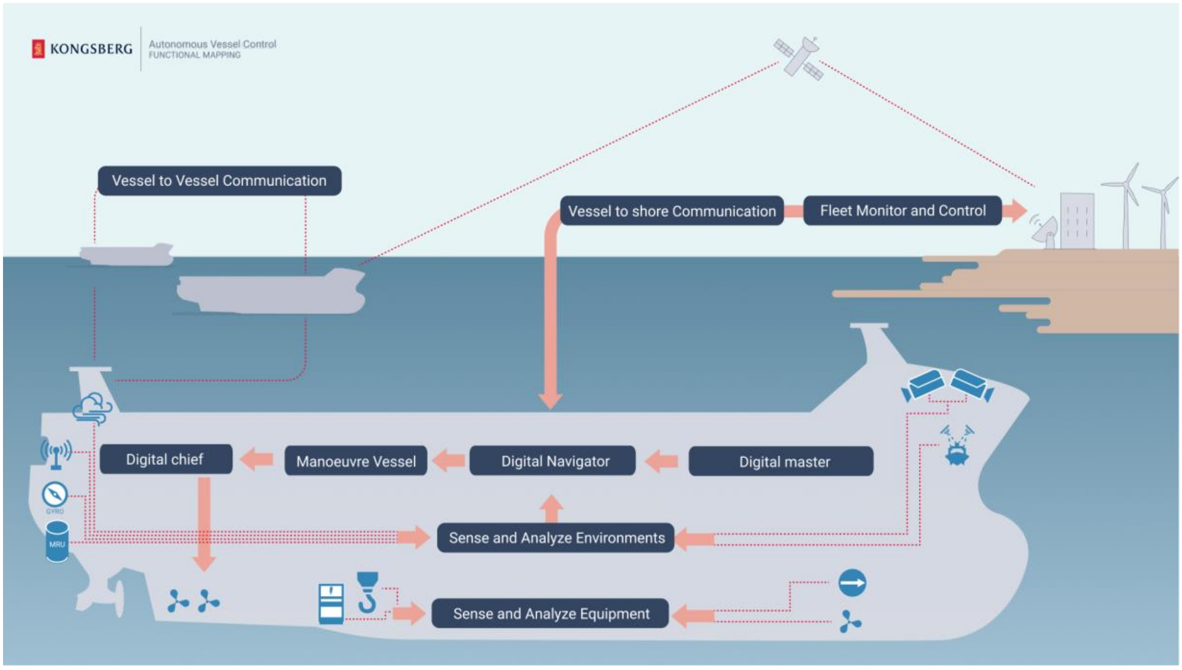

Figure 18 An overview of the autonomous ship system concept by Kongsberg Maritime

9.1. KET: SITUATIONAL AWARENESS (SA)

The service that the SA system must provide is an understanding of the current ship capability, its surrounding environment, and by that a sufficiently accurate decision basis for the Autonomous Navigation System (ANS - see section 9.2) to enable safe decision making by the ANS.

The SA 19 (Parasuraman, Sheridan, & Wickens, 2000) is typically implemented by algorithms that fuse the data from several sensors to create an understanding of the current situation. This is analogous to the human lookout on conventional ships. The human senses the environment and ship condition by eyesight, hearing, and feeling the motions of the ship. Of course, also by reading various bridge system statuses. All this information is processed into a perceived understanding of the situation and forms a basis for decision making and response selection. This process of human information processing is modelled as a four-stage model in (Parasuraman, Sheridan, & Wickens, 2000) and illustrated by them as in Figure 20.

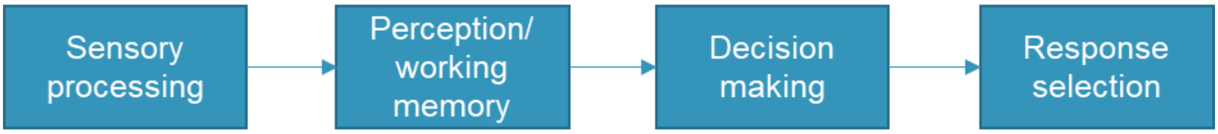

Figure 20 The simple four-stage model of human information processing by (Parasuraman, Sheridan, & Wickens, 2000)

The SA is intended to replace the human lookout, thus, using the four-stage model as an example, it is responsible for the stages "Sensory processing" and "perception/working memory". In other words, to gather all available information, interpret it to understand the current situation, and to predict the near-future development of the situation (e.g., tracking of objects).

The initial work on situational awareness for autonomous ships focused on data collection from several sensors like radar, camera, AIS and positioning, in diverse scenarios, and on research on how this data can be fused to extract the information one needs to create the situational awareness. In 2019 the research and development efforts into the Kongsberg Maritime SeaAware platform for sensor fusion started. This system is today installed on 5 vessels, including the MV Eidsvaag Pioner.

The SA system has been validated as a decision support system connected to live sensor data at a scaled demonstration, i.e., TRL5 (Foss & Skogvold, 2021).

In the AUTOSHIP project, the SA system has been further developed to a level where it can function as the SA for the navigation system of an autonomous ship (the ANS). In 2023 the AUTOSHIP project will also perform two full-scale prototype demonstrations in an operational environment, which means that the TRL at the end of the AUTOSHIP project will be 7.

As will be elaborated in section 11, there are already commercial initiatives with concrete plans for autonomous ship operations within the short term, where this KET is part of the autonomous ship system. This means that it is expected that TRL9 is achieved within the short-term perspective.

9.2. KET: AUTONOMOUS NAVIGATION SYSTEM (ANS)

The Autonomous Navigation System (ANS) is responsible for a series of actions required for safe and efficient autonomous navigation, such as:

- Mission execution
- Fallback state handling and entering MRCs
- Voyage control (route monitoring, re-routing, reporting)
- Obstacle and grounding avoidance
- Route validation

The ANS interfaces several other systems on board the vessel. Data from the onboard object detection system, i.e., the Situational Awareness system, and chart information from the ECDIS are both crucial inputs for the ANS to assess and act upon collision risks. As ANS navigates the vessel at a high level, the system requires an interface to the vessel manoeuvring system which controls the actual thrust output to the propulsion system. ANS also communicates with the Intelligent Machinery System to request changes to the vessel mode setup and get information on vessel capabilities.

One of the first product that started the journey towards more autonomous navigation systems, was the Autocrossing system. The first Autocrossing systems were delivered for road ferries around 2017. These were systems that would automatically sail a ferry across a fjord, ensuring an optimal acceleration and speed profile according to timetables.

In 2018, the first version of the Kongsberg Autonomous Navigation System was born. After the SISU project, Kongsberg continued with the SVAN project together with Finferries, where a ferry was retrofitted with systems for remote and autonomous control, thereby combining the experiences from Autocrossing and remote control. This was the first step towards full autonomy, where the first version of collision avoidance was implemented and tested in a full-scale demo. The same project also included an automatic docking system, which extended the automatic operation of the Autocrossing system to be capable of handling the full operation from dock to dock.

Auto-docking functionality has been continuously improved since the first demonstration in the SVAN project. Auto-docking solutions for ferries have been refined and used in commercial operations.

As a requirement for the ANS to be able to actively control the vessel there is a need to have a good manoeuvring control system, capable of controlling the vessel in all speed regimes. The development of a type-approved track pilot based on much of the same control theory used in the Autocrossing and Auto-docking products has ensured it is possible to upgrade the vessel control systems to a type-approved solution which also supports the new requirements from an autonomy perspective.

The ANS has been validated as a decision support system connected to live sensor data at a scaled demonstration (TRL 5). Integration to control systems have been demonstrated in previous projects (SVAN) in a relevant environment (TRL 7). The overall TRL of the ANS is estimated to be at TRL 5 at the time of writing, and to reach TRL 7 by the end of the AUTOSHIP project.

As will be elaborated in section 11, there are already commercial initiatives with concrete plans for autonomous ship operations within the short term, where this KET is part of the autonomous ship system. This means that it is expected that TRL9 is achieved within the short-term perspective.

9.3. KET: INTELLIGENT MACHINERY SYSTEM (IMS)

The Intelligent Machinery System (IMS) has several responsibilities as it is intended to replace the role of the chief and their team. The IMS communicates with the ANS and receives a mode plan for the voyage, and during operations it receives commands to switch between modes. The mode plan contains the different modes for the different operations during the voyage, the criticality of each operation, and redundancy and power requirements for each operation. The IMS supervises all equipment, and based on equipment and system status, and the requested mode, it decides the best configuration of the powerplant and machinery systems, to fulfil the requirements of the ANS. The IMS issues orders to subsystems such as the power management system to execute the decided configuration, monitors safe transition into a new setup, identifies any failures and takes actions to handle identified faults. The IMS also communicates status on whether it can provide the requested capability to the ANS, monitors system status and alerts, and provides advisory to onshore operation and service centres (i.e., provides own ship situational awareness).

In the AUTOSHIP project, the IMS is a system of systems, where the main technological building blocks are the Digital Chief, the Alert and Resource Management System (ARMS), the Vessel Performance 2.0 advisory system, and the Health Management (or condition monitoring) system.

The technological building blocks making up the IMS did not exist prior to the AUTOSHIP project, except from some early proof of concept software made for the H2020 project NEXUS[7]. The IMS has been validated in a lab environment connected to a machinery simulator and operational control system software,

[7] Horizon 2020 – Project number 774519 NEXUS

in addition to the ANS system, during the AUTOSHIP project. At the time of writing the estimated TRL of the IMS is TRL 4, however the goal is TRL 7 by the end of AUTOSHIP.

As will be elaborated in section 11, there are already commercial initiatives with concrete plans for autonomous ship operations within the short term, where this KET is part of the autonomous ship system. This means that it is expected that TRL9 is achieved within the short-term perspective.

9.4. KET: CONNECTIVITY AND CYBERSECURITY

The connectivity and cybersecurity KET is responsible for a secure and reliable connection between the vessel and the RCC. At the time of writing, communication between autonomous ships, conventional ships, and other stakeholders, depends on the RCC and its operators. In the future, it is likely that direct ship-to-ship, or e.g., ship-to-VTS, communication will be needed, such as discussed in the study on interactions between conventional and unmanned ships (Rødseth, Wennersberg, & Nordahl, 2021). The requirements for standardisation in relation to direct communication between ships and unmanned ships is also discussed in section 9.11.2.

In contrast to the other KETs, connectivity and cybersecurity does not require extensive research and algorithm development specifically for autonomous ships. Communication technology and cybersecurity solutions from other domains, and for conventional ships, are highly applicable, so the development of this KET is more of putting together existing technological components and designing a safe and secure communication system with sufficient bandwidth for the different geographical areas, and operations. The main challenge has been related to keeping the design simplicity, considering the diverse and contradicting requirements of the involved stakeholders and subsystems with their specifications.

In the AUTOSHIP project, Kongsberg has developed a new product called K-Connect. A first complete version of this product was released in the second quarter of 2022 and is estimated to be at TRL7. The K-Connect ensures reliable and secure connectivity between the vessel and the RCC. It includes redundant routers, network, Intrusion Detection System (IDS), and a computational platform for processing and prioritization of traffic. It also supports redundant and diverse carriers like 4G, 5G, WireGig, MBR and Satellite.

The K-Connect is released in a new version and installed on the Eidsvaag Pioner, ready for the demonstration in 2023. In fact, Kongsberg Maritime have planned two new releases of their K-Connect product during 2023, and is targeting to reach TRL9 by the end of 2023, which means that the TRL when AUTOSHIP ends (or possibly within a very short time after the project completion) will be TRL9.

9.5. KET: REMOTE CONTROL CENTRE

The Remote Control Centre (RCC) is a site remote from the vessel from which monitoring and control of some or all vessel functions can be executed. The vessel can be uncrewed, or it can have some automatic or autonomous functions and be crewed. The RCC operator station design is not intended to be a replication of the ship bridge. Instead, it is designed with a focus on the RCC operator and their work tasks. Video feeds, sensor data, Radar and ECDIS screens, etc., can all be displayed on the operator station screens. Criticality and frequency of use are important design factors for the layout. Operation mode or phase (e.g., docking vs Navigating open waters), or fault conditions, also influences what data and information is presented and where. All of this to give the RCC operator the best possible situational awareness.

The starting point for the RCC development in AUTOSHIP was through the SISU project, that was done together with Svitzer. Existing technology was used to demonstrate how far one could go towards remote control using existing systems in a new way. The Svitzer Hermod, a 28-meter tug, was controlled in direct remote control of thruster levers from a human operator in an RCC. There were persons onboard, but only for assuring safety. The demonstration focused on remote watchkeeping by hearing and sight, navigation, and manoeuvring. There were persons onboard for assuring safety, and for monitoring and control of all other vessel systems.

In 2018, a second version of the RCC was demonstrated. After the SISU project, Kongsberg continued with the SVAN project together with Finferries. The SVAN project retrofitted a ferry with systems for remote and autonomous control, thereby combining experiences from autocrossing and remote control. This was the first step towards full autonomy, where a remote operator in the RCC was monitoring and supervising autonomous control systems onboard. In the demo for the SVAN project, there were also crew onboard for monitoring and control of all vessel systems.

The RCC system has been validated in a laboratory environment (TRL 4). Integration to situational awareness, control systems and connectivity systems have been demonstrated in previous projects (SISU and SVAN) in a relevant environment (TRL 7), but for lower autonomation levels. SISU demonstrated direct lever control of thrusters from an RCC, while SVAN demonstrated remote supervision of some autonomous control systems onboard.

The RCC system is an integrated system hosting the services provided by other KETs. The assessment of the overall TRL level of the RCC is challenging since some subsystem integrations has been started, but some subsystems are not yet available for integration. The overall TRL of the RCC KET is estimated to be at a TRL level 4-5 at the time of writing this report, with a goal of reaching TRL 7 by the end of the AUTOSHIP project.

As will be elaborated in section 11, there are already commercial initiatives with concrete plans for autonomous ship operations within the short term, where this KET is part of the autonomous ship system. This means that it is expected that TRL9 is achieved within the short-term perspective.

9.6. KETS DEVELOPED BY OTHERS THAN AUTOSHIP PARTNERS

There are other actors than the AUTOSHIP partners that are developing the KETs SA, ANS, IMS, Connectivity and Cybersecurity and RCC. However, our access to more detailed information on the status of their developments is limited to news articles and publications published on the internet. It is therefore not possible to give accurate estimates of their TRL level, however, in the section 11 we will discuss the known commercial initiatives, and thus indirectly the maturity of the various other known technological developments.

9.7. KET: TRL AND RELATION TO AUTONOMY LEVEL

The technological readiness level for KETs, as discussed in the previous sections, does not really give any indication on what autonomy level the KETs support. It is also important to note that the autonomy level of the system constructed from the KETs does not only depend on the KET capabilities. In addition, we need to consider legal constraints, and issues such as maintenance, which, at least for some years to come, will constrain the autonomy level of ships even if the KETs do not.

To better understand the relation between autonomy level and TRL development steps, we need to provide a brief discussion on autonomy levels. The basic differences of autonomy levels are discussed in (Rødseth, Wennersberg, & Nordahl, 2022) in terms of how responsibility is shared by automation and the human operator. The following is based on the discussions therein: At the most basic level, the operator is responsible for all functions, and they are executed manually or by limited automation that must be continuously supervised and controlled. This is called *OE (Operator Exclusive)*. The next level is when automation can control the execution of the function, but with continuous attention from the crew. That is, it is not possible to determine a period for which automation can be in control and unattended, and the crew is expected to be able to take immediate action when this is needed. As an example, the automation is not capable of making decisions such as altering the course, or changing speed, to avoid collisions, but it can maintain course and speed given by a route plan. This is called *OA (Operator and Automation).* The next level is when the automation can control the function for a known period without human attention. This implies that there are defined and measurable conditions for when the automation can be in control, such that it is possible to calculate the period it can be in control without human attention. This is called *CA (Constrained Autonomy).* As an example, given that certain conditions are met for the defined period into the future, the automation can make decisions such as altering the course or speed, deviating from the planned route, e.g., to avoid collision. If the situation changes such that the period that the automation can be in control drops below a certain limit, an alert is issued to the crew such that they can get safely back in control. An example of this is if the traffic situation gradually becomes more complex such that automation can guarantee safe operations for a shorter and short period, until it reaches a limit at which it alerts the crew to take over. The final level is *FA* where automation can control the function for as long as needed, for all design conditions, without human attention.

These levels provide a convenient method for defining the autonomy level of functions and systems for documentation and approval; however, they are less useful for describing the actual implementation of an autonomous ship system (Rødseth, Wennersberg, & Nordahl, 2022). A more descriptive scale for this purpose is given in Table 2, and is also based on (Rødseth, Wennersberg, & Nordahl, 2022). If we consider the requirements to KETs implied by each level in Table 2, we can see that KETs must evolve in steps. Initially, to support autonomy levels AO and RC we need ships with conventional automation systems (*OA*), either directly controlled by crew, or by operators in RCCs. While AO operations are state of the art, RC operations require that KETs are adapted to be controllable from an RCC. Some KETs are at TRL9 for some RC applications already. As an example, SEAFAR currently operate ships at the RC level in inland waterways, while Yara Birkeland and the ASKO ferries are soon to follow in shortsea.

The next autonomy levels, PU and CA, are more complicated. In these levels, certain decisions will be made autonomously by the automation (by *constrained autonomy)*, while other decisions require a handover of control to humans; either the crew onboard (in case of PU) or operators in an RCC (in case of CA). The division of responsibility between automation and human operators must be clearly defined, as well as the conditions for which the responsibility divisions apply. These levels are, however, harder to define in terms of TRL because it depends on the intended design what functions, under what conditions, shall be handled by the automation. This means that at one point in time it is likely that TRL will be different for different applications. As an example, coastal shuttles in limited areas could be at TRL 9 for CA, while in other applications, e.g., shortsea between Norway and Belgium, TRL could be 9 for PU but not for CA.

The final autonomy level is FA. In this level, all decisions are made by the automation systems autonomously. The RCC is still needed, however, its only role is for fallback handling.

This means that KET development will continue after the first operations at TRL9 (RC), for quite some time to come. Step by step, PU, CA, and FA will be achieved for all relevant functions, for applicational areas one after the other.

Table 2 Autonomy levels as defined in (Rødseth, Wennersberg, & Nordahl, 2022), with some slight changes.

Autonomy level	Definition
AO: Automatic Operation	Examples could be dynamic positioning, automatic berthing, or automatic crossing, where automation performs operations under continuous supervision. All decisions (such as changing route) are made by the automation system operator.
RC: Remote Control	In this case the ship would be continuously supervised from shore, either all the time or, e.g., during night-time. This normally uses AO autonomy level automation with interface for remote control. Though functions are executed automatically, all decisions to make changes, such as re-routing or deviating from a plan, are made by the RCC operator. Furthermore, when used to realise unmanned ships, the ship systems must be capable of maintaining safety in the event of loss of communication with the RCC, which includes the initiation and execution of fallbacks.
PU: Periodically Unattended	The ship can steer itself automatically for extended periods, e.g., in open waters and calm weather. Crew is available onboard to handle more complex situations, but can be away from the controls and, possibly, at sleep during night-time. This normally uses constrained autonomy to enable periods of unattended operations, and crew is alerted in time to gain situational awareness and take over control in case a situation that the automation cannot handle is developing. Certain decisions are made by the automation, and there are clear definitions of the criteria for what decisions automation can make.
CA: Constrained autonomy	Uncrewed operation with constrained autonomy onboard but with operators in RCC that can handle more complex situations. This corresponds to PU but without crew onboard. Certain decisions are made by the automation, and there are clear definitions of the criteria for what decisions automation can make.
FA: Full autonomy	The ship handles all foreseeable situations by itself and there is no crew neither on ship nor in RCC that has any responsibility for any function within the intended design. RCC operators can however be involved in fallback handling and for recovery from fallbacks. All decisions are made by the automation systems on board.

9.8. AUTO-MOORING

A gap analysis on automated mooring systems has been made as part of the SFI Autoship project (Bellingmo & Jørgensen, 2022). The gap analysis discusses magnetic, vacuum based, and robotic arm auto-mooring systems.

Some commercial products based on vacuum and magnetism are already available, though smaller ships, especially ships of composite materials, can't use these (lack of magnetism and insufficient material strength for the vacuum solution). This means that for ships that can use the vacuum or magnetism-based solutions, the technology is already at TRL9. One thing to notice, however, is that (Bellingmo & Jørgensen, 2022) points out that there are some concerns around the daily operational stability of these solutions, which needs to be resolved to ensure efficiency of the operations.

For the remaining ships, the solution might be robotic arms that can pick-up mooring lines and fasten them to existing bollards. Such solutions also have the benefit that no dedicated infrastructure is needed at the quay side. The Yara Birkeland is the first ship that is intended to be moored by such a solution, supplied by MacGregor, and MacGregor is continuing the development of the solution within the SEAMLESS project[8]. In the SEAMLESS project, the intention is to extend the functionality of the MacGragor robotic arm for mooring to also handle the connection and disconnection of charging cables for batteries. Though the expected TRL at the end of SEAMLESS is TRL5, the MacGregor crane used for mooring only is to be part of the unmanned operation of the Yara Birkeland targeted by end of 2024. With this in mind, it is likely that auto-mooring for most ships will be at TRL9 in the short term.

9.9. CARGO HANDLING

Automated or autonomous cargo handling is often an assumed ingredient to maritime autonomous cargo ship systems. It is, however, debatable if it is strictly required to realise commercial operations of an autonomous ship-based supply chain. There are likely both efficiency gains and cost reduction potentials for automating cargo handling. And one can find examples both where traditional cargo handling solutions would be sufficient, and insufficient. One example is the loading of fish feed for the SSS demonstrator ship. This operation is today performed by one of the crew members who opens the feed silo hatches manually and proceeds to control the feed loading crane by use of a remote-controller. In this case, one would need actuated feed silo hatches, but the cranes could be controlled by a person in the same way as today. Or even, from a remote location such as an RCC, given that a video feed was supplied, and the operational area was closed off for people. On the other hand, the discharging of feed to the fish feed factory silos would probably have to be automated on an unmanned fish feed carrier. This operation is done while the

[8] Funded by Horizon Europe Framework Programme (HORIZON), star up 01.01.2023

ship is not moored, but instead keeping position by dynamic positioning. Again, one could envision a remote-control solution, however, bandwidth and video-feed latency, would probably make this a risky operation, and thus infeasible, especially since the ship position is significantly less stable during discharging (un-moored) than during loading (moored).

This example shows that whether automated or autonomous cargo handling is required or not, will be very case dependent. And when we consider large scale international autonomous shipping, it is fair to assume that several loading and offloading processes would have to be automated or autonomous for unmanned ships. Furthermore, while efficiency improvements, and emission and cost reduction might be the most important driver for autonomous ships, the safety gains are probably the most important driver for automated and unmanned cargo handling. Cargo handling today involves several manual work tasks in the operational area of the cranes and lifted cargo. Workers are exposed to significant risks, and the potential for reducing accidents and serious injuries to people is significant if cargo handling was automated. This means that even without autonomous ships, there are strong incentives for automating cargo handling.

The AUTOSHIP project has not done a study on the state of art or feasibility of automated cargo handling, as cargo handling is not within the scope of the project. However, the state-of-art within automated or autonomous cargo handling was studied by SFI Autoship (Mørkrid, Bellingmo, & Wille, 2023). The focus was on general cargo ships and on container ships. The conclusion was that there are several major challenges that must be resolved:

- For containers, the biggest challenge is the need for lashing and securing the containers. There are no automated solutions today, nor any known concepts under development apart for smaller ships that can use cell-guides. This means that securing containers requires manual work onboard the ship for the foreseeable future, except for smaller ships that can use cell-guides, such as the Yara Birkeland (Kongsberg Maritime, 2022).
- For general cargo, or break bulk, gripping the cargo is a major challenge since the cargo comes in a variety of shapes. This means that several different automated gripping solutions would have to be developed. There are some initiatives on automated "big-bag" gripping and release, however, most general cargo will require manual labour on board and on the quay for the foreseeable future.

The study in (Mørkrid, Bellingmo, & Wille, 2023) did not deal with all types of cargo, such as cargo in bulk or roro cargo. However, looking at what we can find in the market:

- Cargo in bulk (dry bulk or liquid bulk such as fish feed or oil) is easier to automate as the gripping (or collecting), transferring, and releasing the cargo is simpler. Securing the cargo does typically also not require manual intervention in the same way as e.g., containers. It is reasonable to expect that this type of cargo handling could be automated in the short to medium term, at least in some cases, since one can find some solutions already in operation, such as (iSAM Group, 2022)].

- Ro-ro cargo could be moved either by manned equipment, or autonomous terminal tractors. The latter is under development and a proof of concept was done by e.g., (Konecranes, 2022) (Terberg Special Vehicles, 2022). This type of cargo handling was also not studied in (Mørkrid, Bellingmo, & Wille, 2023), however, given the fact that automated terminal tractors are announced as products, it is likely that we will see such solutions being taken up in the industry in the short to medium term.

Other important enablers for automated cargo handling are digitalised and automated cargo logistics planning, and cargo stowage planning. These topics will be addressed in the SEAMLESS project, which started in January 2023. There will be some demonstrations in the SEAMLESS project however, the expected TRL at the end of the project for the logistics and stowage planning and execution technologies are TRL5. The SEAMLESS project ends in 2027, which, combined with the status of the different cargo handling solutions, and the evaluation of the technological readiness in (Mørkrid, Bellingmo, & Wille, 2023), gives an indication that automated cargo handling for large scale commercial autonomous shipping lies somewhere in the long term.

9.10. MAINTENANCE OF UNMANNED SHIPS

When the crew is removed from the ships, maintenance and repairs can no longer be performed during sailing (Chae, Kim, & Kim, 2020). An unmanned ship can also not dynamically order supply replenishment from any random port, which indicates that liner trade will be best suited for initial applications of autonomous ships (Wang, Xiao, Li, & Chen, 2020). This requires the research and development of new maintenance regimes (Chae, Kim, & Kim, 2020), (Wang, Xiao, Li, & Chen, 2020). Maintenance is therefore considered an urgent issue which must be solved to enable the realisation of autonomous ships (Wang, Xiao, Li, & Chen, 2020).

While maintenance of unmanned ships is considered a showstopper for unmanned long-distance sailing, it is expected that maintenance can be handled by boarding teams for shorter distances with frequent port calls (Kretschmann & Burmeister, 2017). Another approach to dealing with this problem is to further develop technology for monitoring the ship systems and predicting maintenance and service needs. Some such systems already exist; however, they do not cover all possible components or systems. Other possible solutions lie in new green energy and machinery solutions, however, some of these, like batteries, gives limited range, some are at an early development stage, and yet others might have the same or higher maintenance needs (such as combustion engines on new fuel types).

This means that for short distances, like in inland waterways and some shortsea routes, maintenance is a problem that can be overcome in the short term, while in others, like longer shortsea routes or deep-sea shipping, maintenance might be an unresolved issue well into the long term.

9.11. STANDARDIZATION AND INTEROPERABILITY

Standardisation will be key to the wider adoption of autonomous ships as it can ensure interoperability between products of different makers, between ships of different make with different owners, between RCCs and different ships, between ports and ships, and it may reduce the need to support various variants of technology that solves the same problem. The standardisation needs ranges from technology and components to data exchange, communication, and port clearance.

Some key benefits of standardisation are:

- Improved clarity and predictability, which helps to avoid surprises and reduces investment risk (you get what you expect)
- Reduced cost and time through serial production vs one-off production, which is an enabler for mass-production of products (maybe even for ships or RCC operator stations).
- Improved competition (several providers can provide the same product or service)
- Simplified assurance, compliance, and approval
- Consistent and improved quality through knowledge retention (and experience transfer between designs, projects, and deliveries)
- Improved efficiency, reduced production cost, reduced volume of parts and spares in store, which in turn reduces waste

In more practical terms, standard work processes, performance, interfaces, components, communication, data exchange, and even of systems, can result in:

- RCCs and Ports can service a wider range of ships with equipment from different makers without special adaptations for each ship. As pointed out by (Tsvetkova & Hellstrøm, 2022), standardisation is also necessary to allow autonomous ships to enter ports.
- Communication between ships, between ships and RCC, or ships and port, can be digitalised and automated. This is necessary to enable unmanned ships, unless RCC operators are to handle this communication manually.
- Maintenance and service teams, or energy replenishment facilities, can service ships from different owners with equipment from different suppliers. This could enable business models like "maintenance as a service" or "energy as a service" offered at ports or other key points that autonomous ships would frequently visit.

9.11.1. Types of standards and the approval process

On a high level, standards can be categorised in several different ways, but for the purposes of this document, the most important types are Process Standards, Documentation Standards, Interoperability Standards, Performance Standards and Test Standards.

Process Standards are standards that prescribe how certain processes should be performed. One can include the international safety management code as such a standard, and the ISO 9000 series are well known quality process standards. Examples on what these standards prescribe are how a quality system can be made, how the software or hardware development process should be done, how to define functions, and so on. One could say that the intention of these standards is that "if you do it in this way, the chance of failure is reduced".

Documentation standards are standards defining the process of documenting the correctness of functionality, be it single equipment function or system function.

Interoperability standards are standards that shall ensure that interacting systems are compatible. They are standards ensuring that the exchange of data, signals, or information between two different equipment, or systems, is correct. It can be interface standards in terms of software or hardware interfaces, communications standards like protocols, or standards for the information content that is exchanged through a connection.

Performance standards defines a function and the required performance (e.g., in terms of thresholds) that must be met to be accepted for onboard use, or the results a certain system shall provide. They do not specify how. The performance standards for maritime equipment are normally published by IMO.

Test standards defines how a function shall be tested to validate its required performance. In the maritime domain these standards often translate performance standards to concrete test procedures and expected results. They are normally developed by IEC or ISO.

The approval process of the use of a function, or equipment, onboard a ship depends on if there are existing applicable standards, see Figure 21. For a function, or equipment implementing a function, there is either an existing performance standard or not. Often the equipment implementing this function is standalone (e.g., a GNSS receiver, a radar, or an autopilot), but in some cases it is an integrated function, realised by several pieces of equipment, e.g., an integrated navigation system (INS).

If there is an existing performance standard for the function, it defines the intended functionality and required performance that must be met for the equipment to be accepted for onboard use. A test standard defines how functionality and performance shall be tested and what test results are acceptable. If the function is of the integrated type, the test standard will normally apply to all the equipment related to the integrated function. The manufacturer of such equipment needs to test the equipment according to the relevant test standard(s) to get type approval from a recognised test organisation. When such equipment is used on a ship, no further documentation is required as to prove the equipment's adherence to the performance requirements, however, operators or installers manuals will normally be required, and if so, may also be covered by the test standard.

If the performance standard does not exist, the manufacturer must define the intended functionality through a specification of functionality as well as the performance acceptance criteria (see Figure 21). This will normally include an analysis of the intended operations and functional requirements in various operational modes. This will also require a risk analysis and documentation of risk abatement provisions. Based on these documents the manufacturer must define the test procedures and expected test results. Finally, all documentation must be provided to the flag state or to a suitable recognised organization for approval. This process is documented in (IMO, 2013).

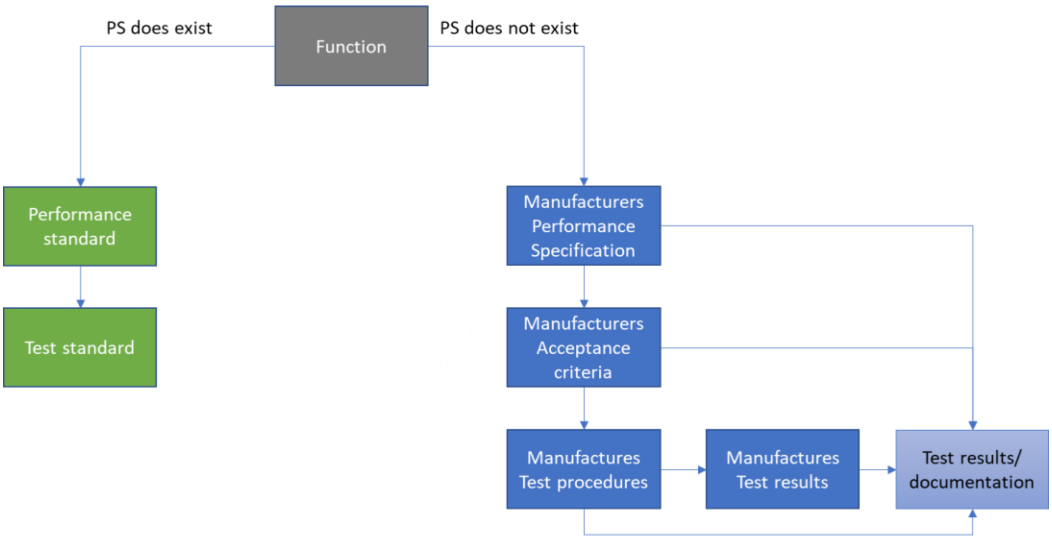

Figure 21 Approval for onboard use of functions and equipment depending on if performance standards exist or not.

In the cases where performance standards do not exist, one may use process standards that can give guidance on how to perform the different activities related to approval, see Figure 22. This would simplify the procedures themselves and would also give additional proof to the approval authority that the procedures are well designed and, hence, that test procedures and results are reliable. Some process standards can also be used as risk abatement components, e.g., the use of a software development quality standard would reduce the probability of there being errors in the software code. Many of the classification societies have published guidance in various levels of details that in some cases can be used as process standards. However, these guidance documents have no internationally accepted status as standards.

To simplify approval, one would desire to have performance standards for all functions rather than using the more complex and work intensive procedures indicated above. However, for some functions, one may find that it is difficult to develop performance standards as the usage scenarios are too varied or that the required performance is too dependent on other external factors. In these cases, one can simplify the case-by-case process by also developing documentation and more specific process standards. These would give more specific requirements to how tests are designed and how specifications, acceptance criteria and test procedures (and results) shall be documented, or how documentation could be produced (e.g., how is a risk or hazard analysis done).

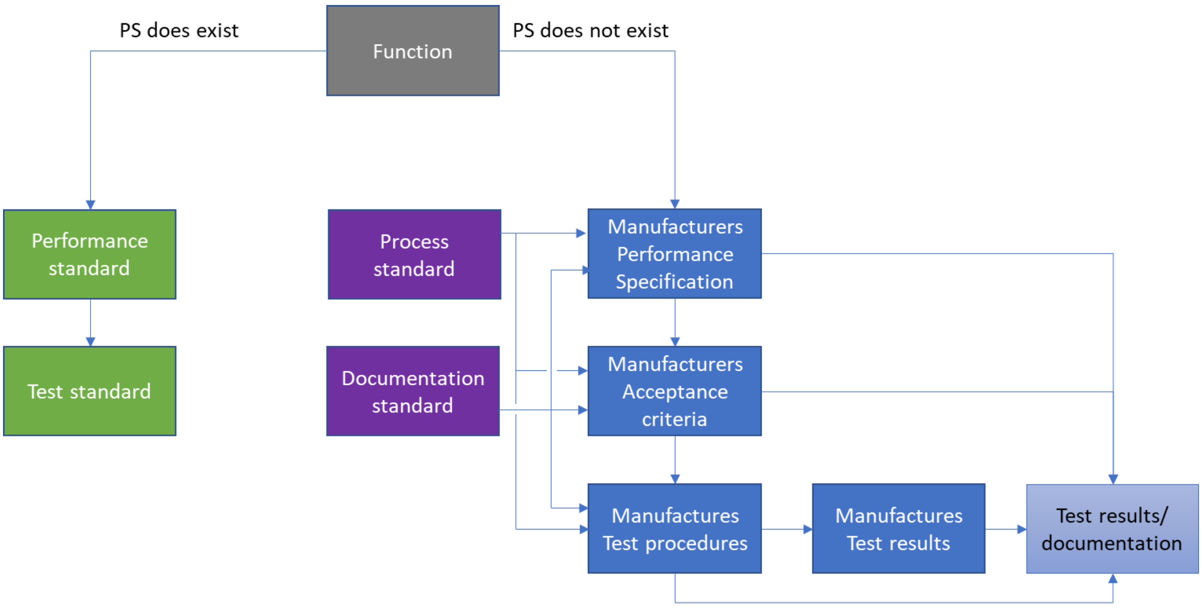

Figure 22 Simplifying approval by using process and documentation standards.

Interoperability standards can be developed for specific equipment if there is a defined concept for an integrated system including the relevant pieces of equipment, i.e., one that sends data and one that receives it, see Figure 23. This will define, e.g., what data a GNSS receiver should transmit based on what data the receiving equipment requires. If interoperability standards are defined for the relevant equipment, tests will be included in the test standards to verify that sending and receiving of data works as expected.

Interoperability standards will also be useful for equipment of the case-by-case approval type to get information about how interfaces to other equipment shall be designed. One may also use these as "blueprints" for own internal interfaces between case-by-case approved equipment.

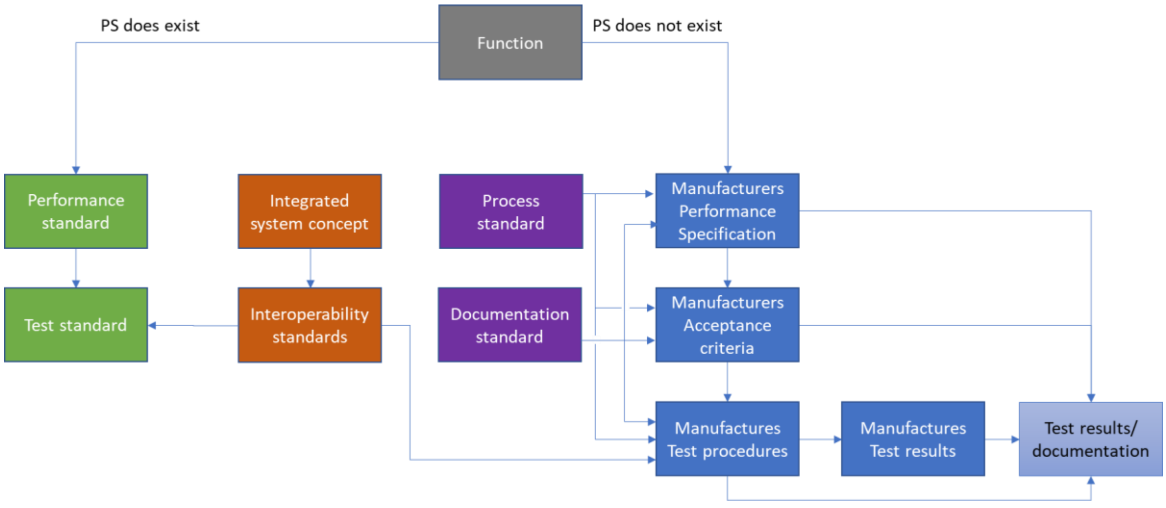

Figure 23 Simplifying approval by using interoperability standards

Today's approval regime is based on equipment type approval, including tests of the equipment's interfaces to other equipment. There are virtually no standards available that address system integration to achieve certain functionality or to test wider properties of an integrated system. Integration tests are performed by the flag state or its recognised organizations during tests on the finished ship, e.g., as part of the sea trials. One may also use factory acceptance tests (e.g., hardware-in-the-loop) or site acceptance tests (e.g., commissioning) as part of the integration tests, but in general it will be necessary to have the whole ship operational before the final tests are performed. In the future there may also be a need for system integration standards that takes a wider view of the system, although it is unlikely that they will cover the full system functionality.

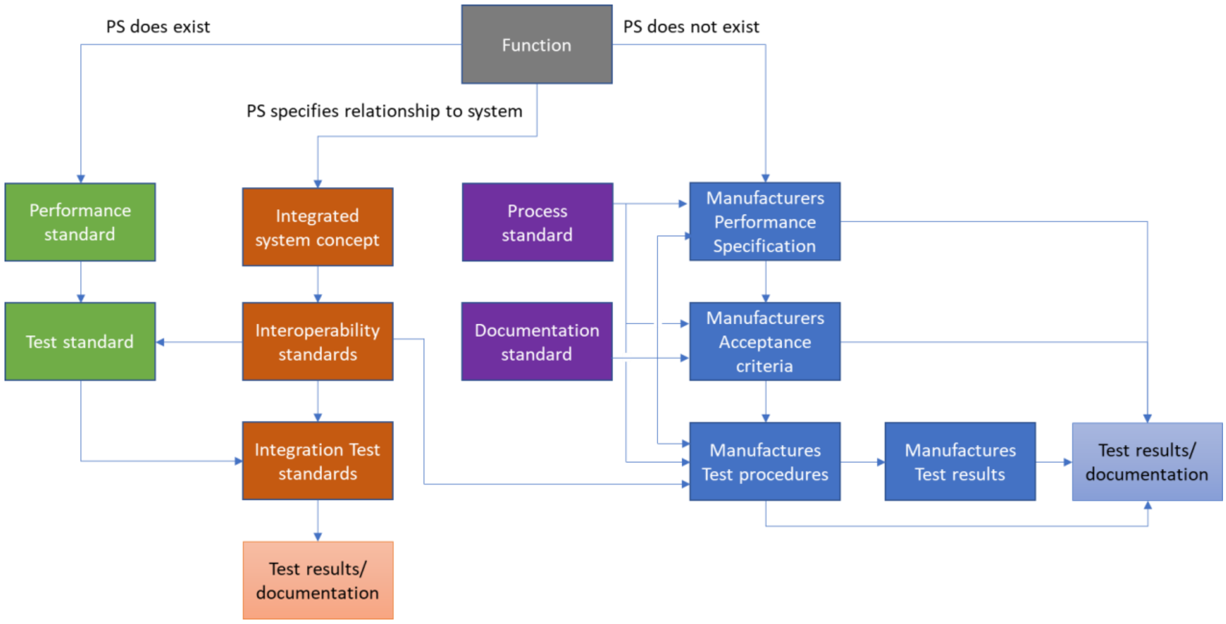

Figure 24 Simplifying approval by using integration test standards

9.11.2. Interactions between uncrewed and crewed ships

Interactions between conventional ships are mainly through AIS and VHF voice communication. In addition, lanterns, other light signals, and sound signals are used. These mechanisms can to some degree be automated on the autonomous ship, but it is likely that voice communication and possibly some of the light signals need to be processed by the human RCC operator.

The AUTOSHIP project did a study on the safety of interactions between conventional and autonomous ships (Rødseth, Wennersberg, & Nordahl, 2021). The main conclusions are:

- The main problem is arguably to understand what the other ship is likely to do next and then to plan own actions according to that. This may not be possible when relying on own ship capabilities alone.
- The most likely and effective short-term solution is to assist the autonomous ship with human operators, either residing onboard or in a remote control centre (RCC)
- The best long-term solution may be to improve the information exchange between the ships. This should, if possible be complemented by changes in COLREG.
- Without improvements in communication and regulation it may not be possible to fully deal with the problem of mixed traffic operations. In the general case, one may still require human to intervene when the situation gets too complex.

This means that it is necessary to standardise the exchange of information between ships in interoperability standards based on updated COLREG, and that this standard must enforce the exchange of sufficient data to enable safe interactions, if a large-scale uptake of autonomy in intercontinental maritime logistics shall be possible.

9.11.3. Interactions between automated ships and RCC

Both crewed and uncrewed ships can be supervised by an RCC. For crewed ships, this can be for improving overall safety or for decision support, or it can be for use during periodically uncrewed operations. In the following, we mainly consider supervision from RCC during (periodically) uncrewed operations.

Interactions and communications between uncrewed ships and the RCC will be digital, but the data that needs to be transmitted is highly dependent on the level of autonomy and subsequently the division of function responsibility between the ship automation and the RCC operator. Simply put, the more functions that the operator is responsible for, the more data needs to be communicated and the higher bandwidth is required.

Initially, when there are no standards regulating these interactions, they, can be solved and implemented case-by-case by the technology providers. However, this will not scale well, it will be costly, and it will cause concerns for investors in autonomous ships as the second-hand market will be limited (there is no guarantee that a ship bought second-hand will fit seamlessly into the system where you intend to use it). This is because autonomous ships cannot be expected to be moved and put under the control of another RCC without extensive system adaptions and upgrades, either in the RCC or the ship, or both, when autonomy levels, function responsibility definition, and data and control signal formats are not standardised.

Interoperability standards for the interactions between RCCs and autonomous ships are therefore needed. These standards should include:

- Function definitions
- Standardised responsibility mapping and definitions of conditions that determines the responsibility mapping
- Required data to be exchanged per function depending on who is responsible for the function (automation or RCC operator)
- Interoperability in terms of connectivity (carriers, protocols, etc.), interfaces, sensors, and controls

Once interactions between ships and RCCs are standardised, it will become cheaper and quicker to put a new autonomous ship into operation under the control of an RCC, and it will be significantly easier to move a ship to a new location and under the control of another RCC. Which in turns opens up for the second-hand market and reduced investment risk.

9.11.4. Digital interaction between autonomous ships and shore side parties

Digitalisation of the maritime sector is needed to achieve the necessary level of automation and autonomy. Ships communicates with a range of actors such as the VTS, ports and terminals, pilots and tugs. To facilitate this for autonomous ships (including their RCC), we need to agree on an integrated maritime information architecture covering specifications and standards that spans the parties that the ship needs to communicate with, as illustrated in Figure 25. Note that the green ship represents that autonomous ship and its RCC.

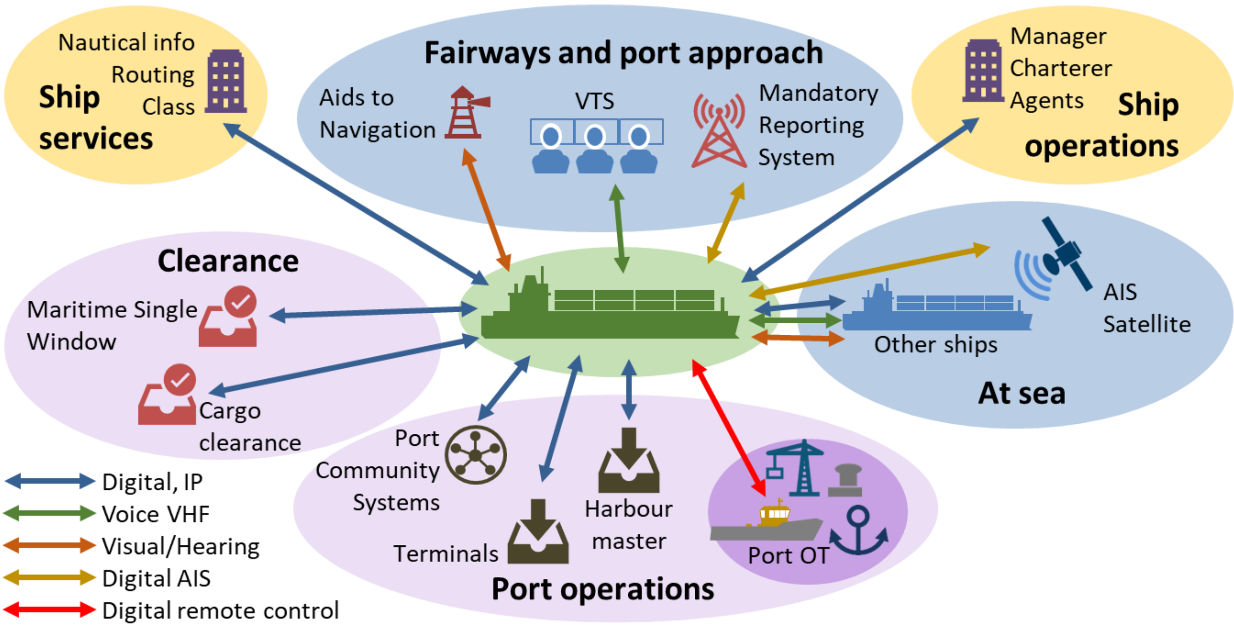

Figure 25 Different parties the ship communicates with

Communication is done with different means as indicated by the colour of the arrows. A fully uncrewed ship needs a digital solution to all these communication methods and standards will obviously be helpful to as far as possible automate the communication processes. For an autonomous ship with RCC assistance, it will not be critical to have standards as humans are available to perform the communication remotely, although standards will reduce the workload and implementation cost for the RCC.

Currently, there is significant activity on digitalisation of communication between ship and shore and a corresponding standardization effort. This is partly through nautical information exchanges, e.g., electronic charts, chart overlays, and other e-navigation developments, coordinated by International Hydrographic Office through the S-100 initiative[9]. It is also an activity to coordinate administrative (business to authorities) and operational (business to business) data exchanges through the IMO Compendium, manged by the

[9]http://s100.iho.int/home/s100-introduction

Facilitation Committee in IMO[10]. While this work is targeted at general automation of administrative tasks onboard conventional ships it will also be of use for uncrewed and more automated ships.

One will also need development of new protocols for digital remote control of automated equipment in ports, e.g., cold ironing, charging, mooring etc., but this is not yet started. Protocols exists, e.g., for automatic mooring systems, but they are currently proprietary.

9.11.5. Physical interoperability between autonomous ships and port

As discussed in section 7, autonomous ships will depend on port infrastructure and to ensure that the business case is viable, several autonomous ships must share this infrastructure. Sharing infrastructure implies a certain level of standardisation such that owners of new autonomous ships can be sure that their ship can be serviced by a certain port given that it adheres to the standard. The most obvious examples of port infrastructure which physical interface must be standardised are cargo handling equipment, automatic mooring, and charging (or fuel bunkering).

9.11.6. Standardisation of equipment and interfaces

The autonomous ship system will be a complex system of integrated equipment, and it is likely that there will be a demand for building these systems based on equipment from different vendors to ensure competition and sufficiently low pricing. However, integrating equipment from different suppliers into a system is a cumbersome and time-consuming process unless interfaces are standardised. Furthermore, if the equipment function or functions are not standardised, it can be hard to predict the integrated system performance. This will complicate the verification and approval process and require extensive testing. It could even result in performance issues during operations. Therefore, when the autonomous ship technology has reached a sufficient maturity level, there will be a need for developing performance standards and interoperability standards. Once such standards are available, verification and approval will be simplified. Furthermore, such standards make manufacturing easier and more streamlined, resulting in reduced production costs, and it simplifies the replacement of one equipment

9.12. SUMMARY

The Key Enabling Technologies for unmanned autonomous shipping is expected to be at TRL7 at the end of the AUTOSHIP project, except for Connectivity and Cybersecurity which is expected to be at TRL9. This requires that the developments towards, and the execution of the AUTOSHIP demonstrators, are successful. The further KET developments towards TRL9 will be in steps. Initially, the KETs will be developed to enable the unmanned autonomous operation of the Yara Birkeland within 2024, and shortly

[10] https://imo.org/en/OurWork/Facilitation/Pages/IMOCompendium.aspx

after, the ASKO ferries and Reach Remote, as elaborated in section 11. It should however be noted that the initial autonomous operations are to be supported by continuous RCC supervision.

This means that the KETs could reach TRL9 within the short to medium term, for some applicational areas, not considering regulatory or maintenance related constraints. Meaning, not all applications of the autonomous technology will be feasible. Consulting (Mørkrid, Bellingmo, & Wille, 2023), which studies the feasibility of shortsea and deep-sea autonomous shipping, we observe that they find it feasible that autonomous navigation can be performed within the short term (within the next 5 years), in all operational phases (near port, coastal and deep-sea), while maintenance and regulations limits the applicational areas of autonomous ships until the long term. This supports our opinion that KETs will probably reach TRL9 within the short term, while autonomous ship operations for all possible ships and application will not be supported in the short term by the KETs, and will need further development, trials, and demonstration efforts.

Gaps as seen from after AUTOSHIP:

- KET development from TRL7 to TRL9 for autonomy level RC:
    - Automation must support remote control and redundancy,
    - RCC must support remote control
    - Safety and automation systems: IMS, and predictive maintenance must be solved
- KET development towards TRL9 for autonomy level CA in addition to steps taken for RC:
    - ANS and SA must enable autonomous navigation under defined conditions (constrained autonomy), the ANS must be able to detect when a handover to crew is required,
    - IMS must be more advanced and provide ship situational awareness. All automation must be constrained autonomous.
    - Operator-automation responsibility model is needed
- KET development towards TRL9 for autonomy level FA in addition to step CA:
    - All functions and operations must be handled autonomously, that is, all automation must be autonomous
    - New internationally accepted rules for interactions (e.g., new COLREGs) must be implemented.
    - RCC must handle fallback recovery
- Trials and full-scale demonstrations of autonomy levels PU, CA, and FA, for various applications

Even though KETs are closing in on TRL 9, for some applications, and are likely to succeed if the developments continue to receive funding, there are other technological issues that will delay large scale unmanned autonomous intercontinental maritime logistics and which should be addressed. Namely maintenance, cargo handling, and standardisation.

Maintenance is an unsolved problem for large scale intercontinental unmanned autonomous shipping. There are cases, such as inland waterways and sheltered water shuttles over shorter distances, where the ships are moored at quays frequently enough to make maintenance concepts such as the boarding teams proposed in (Kretschmann & Burmeister, 2017) viable. However, at a certain point the time between port calls becomes too large to allow for frequent enough maintenance to ensure the integrity of the ship and its systems. Predicted solutions revolve around less maintenance intensive machinery and propulsion solutions, and technical solutions like advanced equipment supervision and maintenance need prediction. However, no unified solution is on the horizon, making maintenance challenges a significant constraint that must be removed. The following gaps must therefore be closed to enable large scale intercontinental autonomous maritime logistics:

- Methods for predicting time to failure and maintenance needs for all critical system components (which requires that high quality and reliable data, such as Mean Time Between Failures, are known and available for all these components)
- Methods for predicting system performance based on component and sub-system failure
- Maintenance schemes based on failure prediction and component failure criticality; optimisation of maintenance activities to maximise system uptime and minimise disturbances from failures and from maintenance activities.
- Required frequency of maintenance must be reduced to ensure safe and reliable operations for longer periods. Less maintenance intensive propulsion and machinery systems are needed.

There are some advancements within automated cargo handling today, however, several major challenges remain to be solved. Container handling is automated in larger ports, but not yet in smaller ports and quays, and container securing remains a problem for ships that cannot use cell-guides. Gripping cargo is an unsolved issue for most cargo types due to significant variation in form of the cargo. However, autonomous operations do not strictly depend on automated cargo handling as land-based crews could perform it while technical solutions are pending. Nevertheless, the following gaps must be closed to realise efficient autonomous intercontinental maritime logistics:

- Container lashing and securing cannot be done without manual labour
- Gripping various cargo types is not solved
- Situational awareness for cargo handling is mostly non-existing - detecting the gripping points, finding the drop-off locations, detecting obstacles and persons.
- Collision avoidance in the general case must be solved. Based on SA, make safe decisions such as replan the path for the crane movements, freeze movements, lower cargo, or go to a safe position, etc.
- Digitised and automated stowage planning, or bay planning, – based on a cargo loading plan, the current ship status (such as current cargo onboard, stability issues, etc.), cargo delivery plan, and

possible special concerns for the cargo, algorithms for generating optimal placements of cargo, loading sequences, etc.

- Digitised and automated logistics planning based on current cargo position and status in the logistic chain, destination, and available candidate transport vessels and vehicles.

All the technological gaps related to cargo handling need to be closed and advanced to TRL9, meaning both scale and full-scale demonstrators will be needed.

Mooring solutions for ships above a certain size are already at TRL 9, however, for the smaller ships that cannot use the magnetism or vacuum based mooring solutions, automatic mooring needs to be solved in the short term to enable the SSS and IWW commercial initiatives, which are part of the road towards large scale international unmanned shipping:

- Solutions like robotic arms for fastening and releasing mooring lines must be advanced to TRL7, and then TRL9
- Scale and full-scale demonstrations of solutions like robotic arms for fastening and releasing mooring lines

Standardisation is key to achieve efficient and competitive large scale unmanned autonomous intercontinental maritime logistics and required to solve some issues like interactions between conventional and unmanned ships (if RCC is not to be involved). The following gaps are identified:

- New process and documentation standards to simplify and improve the validation and assurance process for KETs and related functions that currently do not have performance standards.
- Interoperability standards covering the interfaces and information exchange between KETs
- Performance and test standards for KETs
- Integration test standards for autonomous ship systems
- Interoperability standards for Ship-RCC, Ship-Ship, and Ship to shore-based stakeholders.

10.GAP IDENTIFICATION: LEGAL AND REGULATORY FRAMEWORK

This section covers the legal part of the PESTLE analysis and will identify gaps related to the 1) regulatory framework for maritime shipping and inland waterways, 2) the legal framework, 3) the liability and insurance framework, 4) the certification and approval framework for operators in remote control centres and 5) the classification society guidelines that together will enable large scale uptake of uncrewed autonomous ships supported by operators in remote control centres. The method and baseline for the gap identification is presented first and is then followed by the scope and results of the gap analysis for each framework. A summary of the most important gaps is given at the end of section.

10.1. METHOD AND BASELINE FOR GAP IDENTIFICATION

The frameworks that govern the safety and security of conventional ships assume that humans are onboard for the purposes of e.g., navigating the ship, monitoring the surroundings and the equipment, carry out maintenance, and manage emergencies. The disruptive shift towards uncrewed autonomous ships that is supported by an RCC will thus create gaps as existing regulations, rules and standards typically require explicit human intervention. These gaps create a need for stipulating new and amending existing rules, regulations, and standards. This applies to both the current maritime and inland waterways regulatory framework, at international, regional, and national levels.

Gap analyses of the existing regulatory, legal and liabilities frameworks have been subject to considerable research efforts (CMI, 2016) (Fastvold, 2018) (Ringbom, 2019) (Nzengu, Faivre, Pauwelyn, Bolbot, & Wennersberg, 2021). In addition, IMO has completed its regulatory scoping exercise (IMO, 2021) and the interim guidelines for MASS trials (IMO, 2019) are publicly available.

Most of the material in this section is based on the AUTOSHIP deliverables for regulatory framework mapping and gap analysis (Faivre, Nzengu, & Bolbot, 2019), and regulatory, legal and liabilities framework amendments (Ahmed, et al., 2022). The scope of the analysis in the aforementioned deliverables was limited to relevant rules, regulations and standards applicable to the two AUTOSHIP use cases: a shortsea shipping general cargo ship and an inland waterways barge, including the geographical area of operation, ship specifications and operational profiles.

The methodological approach used for this purpose was based on a definition of three distinct stages: 1) The existing stage, 2) The transition stage and 3) the next generation ship stage. These stages do not correspond one to one with the methodological approach in this roadmap but can be translated to autonomy levels in Section 9.7 that are used as a basis in this report. This relationship is shown in Table 3.

Table 3 - Relationship between the autonomy levels in this report and the stages of the regulatory framework analysis in AUTOSHIP D8.2.

D8.2 (This report)	D7.4/D2.3	Analysis scope
Automatic Operation (AO)	Existing stage IMO 1 CCNR 0 and 1	State of the art (Baseline for analysis)
Remote control (RC) and/or Constrained Autonomy (CA)	Transition stage IMO 2 and 3 CCNR 2,3 and 4	Mapping of frameworks Gap analysis Classification into categories Recommendations
Full autonomy (FA)	Next generation stage IMO 4 CCNR 5	Not analysed

Note that (Ahmed, et al., 2022) refers to the outcome of the Regulatory Scoping Exercising (RSE) (IMO, 2021), which was initiated by IMO to assess the degree of acceptability of MASS operations within the existing regulatory framework. RSE proposes 4 alternative ways to address the instruments which are also adopted in this study by either: (a) developing interpretations or equivalences as provided by the instruments; (b) amending existing instruments and/or (c) developing a new instrument or (d) none of the above, as a result of the analysis.

Based on the identified regulatory gaps, the severity levels of the analysed instruments' provisions are classified as High, Moderate or Low, considering the degree of the human involvement to comply with existing provisions, and the expected timeline of implementing the proposals:

- *High:* Require onboard human intervention.
- *Medium:* Human intervention or system upgrade needed.
- *Low:* Definition-wise amendments.

Highly severe instruments may require longer time to get international acceptance. Therefore, a longer time frame needs to be set up to address these instruments. Alternatively, an exemption could be granted as a temporary solution, or a bi-lateral agreement could be signed among the contracting governments to allow the operation of MASS at its initial phase.

Moderately severe instruments mostly utilise trusted modern technologies to support the alternatives to comply with the existing instruments. Therefore, comparatively less time would be required to get their acceptance internationally or nationally if reliable technologies are used for implementing autonomous functions.

Last but not the least, the instruments that require definition or clarification wise amendment is relatively easy to get worldwide acceptance within a short period of time. These types of instruments could be prioritised to do the amendments in the early phase

These severity levels are intended to aid MASS policy makers to prioritise the instruments which would require amendments before all others while preparing the roadmap for MASS adoption.

10.2. REGULATORY FRAMEWORK

10.2.1. Scope of the Gap analysis

Analysis of the acquired information allowed for identification and mapping of the relevant regulatory bodies in the existing frameworks. These regulatory bodies provide a number of instruments which require specific provisions that must be met for the operation of ships. In (Faivre, Nzengu, & Bolbot, 2019) the analysis of the regulatory framework has been limited to the following mandatory regulatory bodies for the safety and security of the IWW use case:

RPNR, CEVNI, CLNI, CDNI, European Directives, Regional, National and Local regulations.

and the following mandatory regulatory bodies related to maritime safety and security for the SSS use case:

SOLAS, CLL, TMC, STCW, COLREG, SAR Convention, MLC, European Directives, National and Local regulations,

Note that the land-based regulations for remote control centres located at the shore have not been included in the studies in (Faivre, Nzengu, & Bolbot, 2019) and (Ahmed, et al., 2022). The amendments necessary for ships carrying dangerous goods as well as passenger ships have not been considered. Regarding deep-sea shipping, most of the IMO-governed regulatory bodies are covered, as these are mostly the same as for the SSS use case. However, further modification of the proposed recommendation may be required depending on the ships' deep-sea sailing route.

Also note that Full Autonomy is not within the scope of the study in (Ahmed, et al., 2022).

10.2.2. Gap analysis results

The analysis has captured that the meanings of "master", "crew" and "responsible person" need to be clarified at different autonomy levels considering that they are not onboard and that several tasks normally carried out manually by the master or crew need to be managed by the systems on board or remotely by RCC operators. These types of instruments which require definition-wise explanation or amendments to regulations are deemed less severe in getting wide acceptance by international regulatory bodies.

Some instruments require manual operations, indication, or alarm on the bridge. Alternative solutions are needed in compliance with these provisions with equivalent safety levels, where manual operations are suggested to be done remotely or autonomously at different autonomy levels by deploying the Key Enable Technologies (KETs) for the two use cases.

Additionally, the ways to transfer a “physical bridge” to an “electronic bridge” with detailed functionalities of an onboard control system, connectivity and remote control system are also needed to justify the equivalences of some proposed solutions to the existing instruments. Note that it is highly unlikely nor desirable to keep the RCC as similar as possible to the bridge, see discussion in Section 9.5. These types of instruments are deemed moderately severe as trusted modern technologies could be utilised to support the alternatives to comply with the existing instruments.

Apart from that, some instruments explicitly require the presence of humans on board, e.g., render assistance in a distress situation or pilotage requirements. These instruments are suggested to be qualified by the reasonable capabilities and limitations of autonomous ships. Additionally, the provision of getting exemptions from these rules is also highlighted for autonomous ships at regional or national levels. These types of instruments are deemed highly severe as they require more consideration to get acceptance at an international level.

There are some instruments that do not require any amendments as they either do not hinder the autonomous operations of ships directly or the provisions contain exemption criteria for innovation or test purposes.

A total of 78 gaps or needs for amendments was identified for the SSS use case. To get the insights of the required amendments among different regulatory bodies of the SSS use case, Figure 26 (left) is prepared and it shows that 62% of the identified instruments that require amendments belong to SOLAS, 12% belong to COLREG, 6% and 5% belong to STCW and CLL, respectively. The remaining 15% of the instruments belong to the other regulatory bodies.

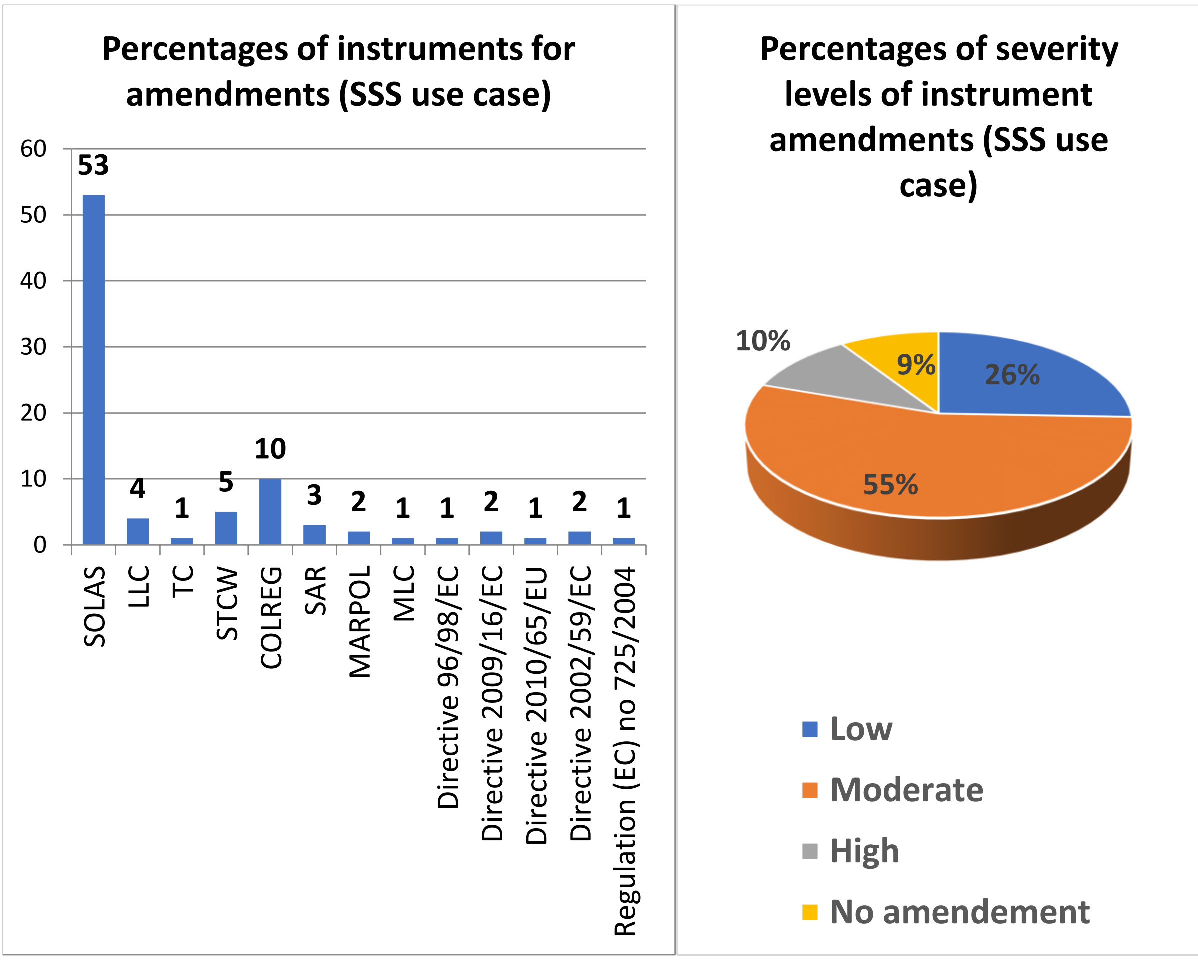

Figure 26 An insight of instrument amendments for regulatory bodies of the AUTOSHIP SSS use case; left percentages of identified instruments for amendments; right: percentages of severity levels for amendments. Based on the analysis in AUTOSSHIP D7.4: (Ahmed, et al., 2022)

This study also considers the severity analysis as shown in Figure 26 (right), which shows that 55% of the instruments are found moderately severe which requires technological support to convince the policy makers for their alternative provisions. With the advancement of the technologies and trials of MASS, more experience will be gathered and utilised to amend these instruments further if required. On the other hand, 10% of the instruments are found to pose high severity as they require explicit human involvement. Temporarily, exemptions could be granted to these instruments or a bilateral agreement between two contracting parties or agreements between states in a broader geographical area could be a solution at this stage. However, getting an international acceptance to these instruments would require longer timelines. This analysis also demonstrates that 26% of instruments require definition or clarification wise amendments and IMO could take initiative to amend these instruments in the short-term. As an example, ISO recently published a list of useful definitions for MASS operation (ISO, 2022), which is one of the requirements identified in this study and considered to have less severity. In addition, 9% of the instruments are found not hindering the MASS operation, therefore, no action is required to amend those.

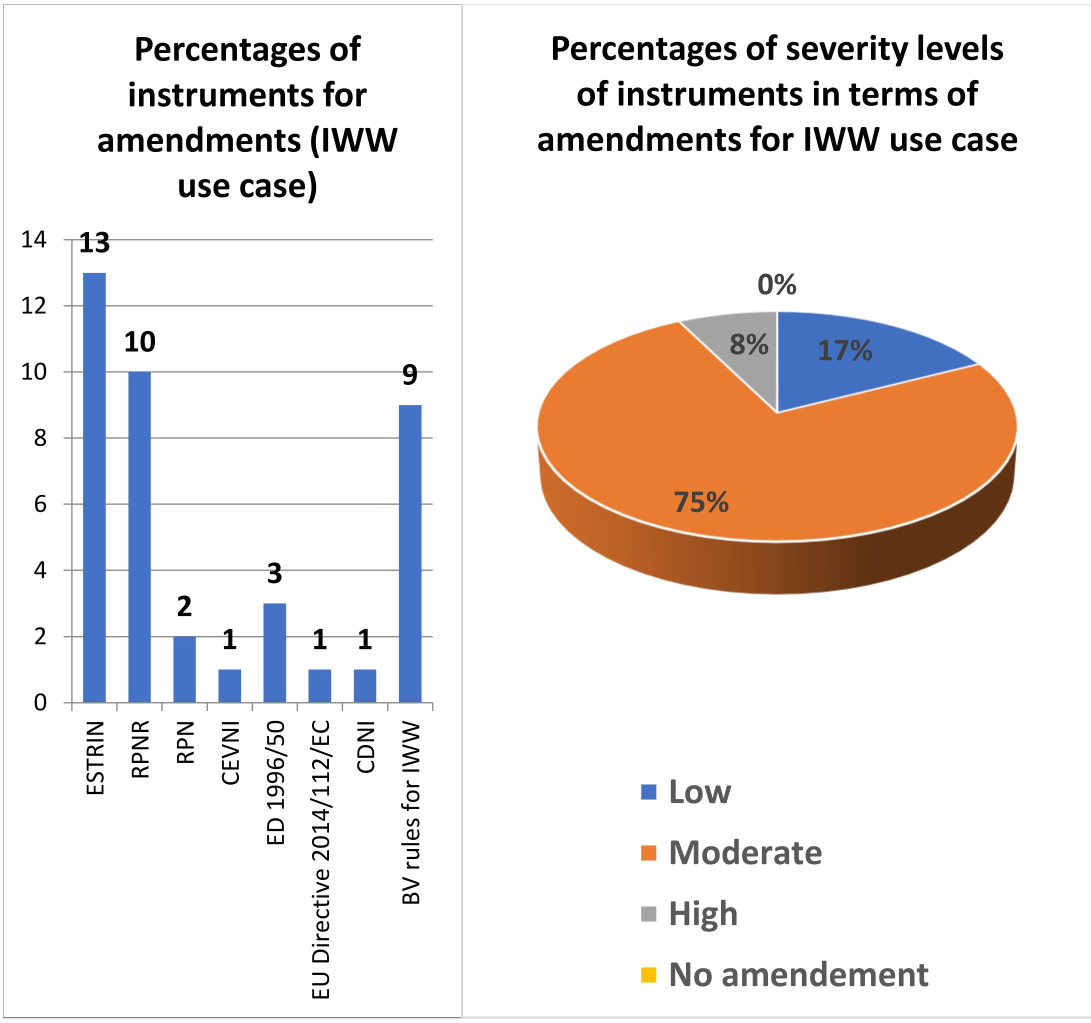

Figure 27 An insight of instrument amendments for regulatory bodies of IWW use case; left: percentages of identified instruments for amendments; right: percentages of severity levels for amendments. Based on the analysis in D7.4: (Ahmed, et al., 2022)

A total of 40 gaps or needs for amendments was identified for the IWW use case. Figure 27 shows that 32% of the identified instruments that require amendments belong to ES-TRIN and 25% and 23% belong to RPNR and BV rules for IWW, respectively. The remaining 20% belong to other regulatory bodies. On the other hand, 75% of the identified instruments are classified to have moderate severity, whereas 17% and 8% of instruments are set to low and highly severe, respectively. There is no instrument identified that does not need any amendment.

Currently, IMO is working on preparing goal-based standards for MASS operation with a non-mandatory MASS code as a first step. This voluntary code is estimated to be completed in 2025. The identified gaps and severity classifications in Figure 26 can be used as input to this process, where the details on required amendments and modifications can be found in (Ahmed, et al., 2022). Similarly, the identified gaps and severity classifications in Figure 27 can together with details in (Ahmed, et al., 2022) be used for similar purposes in IWW regulatory update processes.

10.3. LEGAL FRAMEWORK

10.3.1. Scope of the gap analysis

Legal frameworks include the jurisdiction rules, which lay down the states' rights and obligations to take measure with respect to ships. The legal aspects of the two use cases have been analysed with respect to the current conventions, and in particular the UNCLOS. UNCLOS defines the rights and obligations of states over the seas. The key issues addressed by this body of law include the following: to what extent ships can navigate in different sea areas, what obligations do states have over ships flying their flags, and what rights do other states have to interfere in the navigation of ships in different sea areas.

10.3.2. Gap analysis results

The jurisdiction restrictions and other provisions, such as manning requirements that create barriers to autonomous ships' operability have been identified and relevant proposals are presented in (Ahmed, et al., 2022) at national and international levels. The following gaps have been identified:

- General: Proper definition of 'ships' / 'vessel' is needed to ensure autonomous ships' operability.
- Flag state jurisdiction: There is a lack of well-established rules or regulations for autonomous ships. Which could hinder the wide acceptability of autonomous ships.
- Port and coastal state jurisdiction: An obligation in Article 94(4)(b) require each ship to have a (properly qualified) master and a crew. Furthermore, the right of 'innocent passage' for autonomous ships through other states' territorial seas is not defined. Finally, a port state might not feel safe to give access to autonomous ships, as no commonly agreed rules and regulations exist, which will be a significant limitation of autonomous ships' freedom of movement.

In addition, UNCLOS provision, Article 98(1) presumes that every state shall require the master of a ship flying its flag and it is his obligation to render assistance to persons in danger or distress (also specified in SOLAS Regulation V/33). Another UNCLOS provision presumes that every state shall require the master of a ship flying its flag and it is his obligation to render assistance to persons in danger or distress (Article 98(1)). These rules might have a limited applicability in the context of autonomous ships as there will be no master on board.

The complete list of gaps with proposals for mitigation can be found in (Ahmed, et al., 2022).

10.4. LIABILITY AND INSURANCE FRAMEWORK

10.4.1. Scope of the gap analysis

The liabilities and insurance framework have been analysed with respect to the *Merchant Shipping Act, the 1910 Collision Convention, The Hague and Hague-Visby rules, The 1976 Liability Limitation Convention,* as well as other general and insurance relevant issues.

10.4.2. Gap analysis results

A total of 15 gaps or needs for amendments were found in the liabilities and insurance framework analysis.

Anticipated new players with new risks in the context of uncrewed ships and shifting in liabilities towards the new players have been analysed. Increased liability exposure of shipowners and system suppliers and the issues in determining the insurance pricing for new technologies have also been discussed. Proposals are then included in (Ahmed, et al., 2022) to mitigate these potential gaps in the current liabilities and insurance frameworks.

Regarding liabilities issues, the shipowner will be vicariously liable for the acts and omissions of the remote operator and RCC personnel. Most jurisdictions impose fault-based regimes that require the crew or some other servants to be negligent. However, it does not make sense to refer to the fault-based liability of the shipowner to the extent that navigation is performed, and decisions are taken by the system without any human interference. In such cases, the cause might impose strict liability, which means liability irrespective of fault.

A new risk assessment also needs to be carried out for the new technologies adopted in autonomous ships to understand the coverage required by the insurer and associated insurance premium. Insurers can add or amend clauses using specific wording without having to base themselves on regulations, hence the Insurance framework will be able to adapt faster than the regulatory framework. In addition, there is a high demand that new insurance products need to be developed to ensure the actual coverage needed for cyber risk and the extent of loss for autonomous ships.

As liability and insurance issues are expected to be resolved faster than regulatory issues, they are not considered to be critical in terms of the timeline for large scale international autonomous shipping.

10.5. CERTIFICATION AND APPROVAL OF OPERATORS

10.5.1. Scope of the gap analysis

In conventional shipping, international conventions like Standards of Training, Certification and Watchkeeping (STCW) approve training courses for ship operators and certify the quality of the trainee. An overview of the STCW certificates of competence can be found in AUTOSHIP D7.2 (Jeon, Lee, & Theotokatos, 2022). These certifications are intended to guarantee that qualified operators have the minimum knowledge to maintain safe operations. The quality of RCC operators must also be appropriately ensured. However, as the working environment and organisations of operators are changed in autonomous shipping, the certification and approval process should be modified according to the operations, the technologies, and the business cases. For this purpose, the STCW framework for certification of navigators and engineers have been analysed in the AUTOSHIP deliverable D7.2 (Jeon, Lee, & Theotokatos, 2022), where they find gaps between existing training coverage and the training coverage that is expected for crewless autonomous shipping.

10.5.2. Gap analysis results

The actual certification for ship operators will depend on the autonomy level. For the purpose of certification and approval of operators, the RC and CA autonomy levels represent two major milestones. Note that FA is not analysed in the context of certification and approval of operators.

Remote Control (RC): The enabling technologies are expected to reach a sufficient level to enable crewless operations, but onboard crew might not be removed entirely during this period. Some certificates and approvals of conventional shipping are still required for onboard crews to maintain the safety of the ship and themselves, but requirements for remote operators must be introduced. New training and certification courses for remote operators would therefore be required. The remote operators must be trained to continuously supervise one ship and learn how to act when needed. Human interventions are not necessary for normal operations, however, thorough continuous watchkeeping from the remote operators is required for reliable operations. Both crew and operators need cyber security management training and certification. Additionally, communication and teamwork skills are required for both land-based operators and ship-based crew since autonomous ships are operated collaboratively.

Constrained autonomy (CA): Certificates and approvals for the onboard crews can be removed. No attention will be required for remote operators during autonomous operations. However, remote operators are still required to respond to a request to intervene (RTI) for situations that cannot be handled by the autonomous systems. This means that the remote operator's involvement in the operation will be reduced, but the operator must be more attentive during intervention handling. Moreover, fleet management skills training and certification will be required for remote operators since management of multiple ships per operator will be made possible.

10.6. CLASSIFICATION SOCIETY GUIDELINES

10.6.1. Scope of the gap analysis

Classification Societies (CS) establish and maintain technical standards, rules, and guidelines for amongst other the construction and operation of ships. They provide the rules and regulations for classification and statutory services and assistance to the maritime industry and regulatory bodies regarding maritime safety and pollution prevention, based on the accumulation of maritime knowledge and technology. Class rules are passed and executed by classification societies. In contrast, IMO conventions, codes and other national requirements rules are passed by Flag State and executed by Flag State. Flag States may delegate certain statutory work to a recognised organisation, where this organisation verifies compliance with national and international regulations adapted by a Flag State. Usually, the Flag State selects the classification society to work as the recognised organisation for the survey and inspection of ships. Figure 28 shows the Class-Statutory relationship.

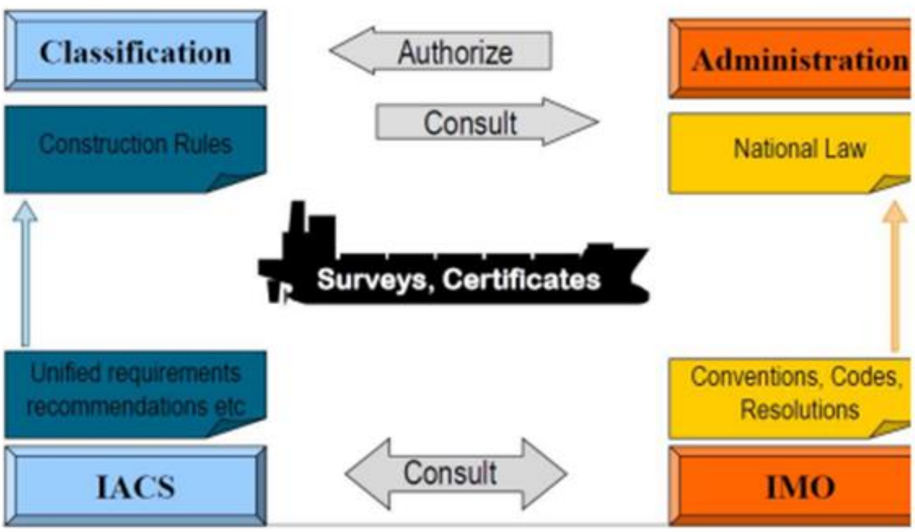

Figure 28: The Classification/Statutory link

In order to understand the development of classification society rules in the context of anticipated MASS development, a systematic analysis has been done in AUTOSHIP D2.6 (Bolbot, Theotokatos, Wennersberg, Faivre, & Nesheim, 2021) The analysis has been conducted for the main classification societies, such as Bureau Veritas (BV), Det Norske Veritas (DNV), Lloyds Register (LR), American Bureau of Shipping (ABS), Class NK (NK) and in addition the umbrella body for the maritime sector Maritime UK.

The complete list of classification societies that have been analysed and the details of the analysis can be found in AUTOSHIP D2.6 (Bolbot, Theotokatos, Wennersberg, Faivre, & Nesheim, 2021). The IMO MSC.1/Circ. 1455 (IMO, 2013) steps have also been employed to check the harmonisation of the classification societies guidelines.

10.6.2. Gap analysis results

It has been found not all the class societies guidance for the MASS are harmonised with the IMO MSC.1/Circ. 1455. LR and ABS guidance for MASS instead are closer to the Maritime UK code for MASS and to the goal-based approaches. In addition, there is no equivalence between the various class societies' guidance for MASS either. This type of discrepancies is anticipated due to the involvement of different expert groups in their development at each class society. However, this is not true for the guidance related to the novel technology introduction, which share some similarities among the investigated class societies (BV, DNV, ABS) and demonstrate strong resemblance to IMO MSC.1/Circ. 1455. Different classification societies could also have different strategies towards approval of MASS or systems that are part of MASS, thus harmonisation itself is not necessarily a gap.

It is also noted that the classification society guidance is more comprehensive under the scope of preliminary design and analysis, which likely is due to the lack of experience on later phases.

Additionally, the basic framework that is used to describe MASS in the guidelines are the Concept of Operations (CONOPS) or similar concepts. This could lead to unstructured and imprecise descriptions of the MASS as there exists various definitions of the CONOPS and the information that is requested by the classification societies differs (Wennersberg, Nordahl, Rødseth, Fjørtoft, & Holte, A framework for description of autonomous ship systems and operations, 2020).

There exists a set of various high-level requirements for the KET on the MASS in the guidance and recommendations. However, there is limited reference to the detailed design of the KET and their analysis method. Such information was mostly found in the class guidance and recommended practices on assurance of novel technology.

Aspects related to AI and ML is not adequately covered. Classification guidelines for MASS needs to focus on how to include AI and ML aspects in the detailed design and analysis of KETs more rigorously. This must be done keeping in mind that integration of AI and ML-functions will provide challenges to the approval process (Murray, et al., 2022):

- The performance of AI and ML models cannot be guaranteed in all situations.
- AI and ML models may perform sub-optimal in unforeseen situations.

Aspects related to verification and testing of autonomous functions are either spread over a series of documents, or no clear process exist for developing and testing the various aspects of the KETs. e.g., safe performance of collision avoidance system. They need to consider consolidation of documentation requirements and test procedures, which is recommended to be harmonised in the class societies recommended practices, codes, and guidance.

10.7. SUMMARY OF GAPS

This section summarises the gaps that have been found in the analyses of the regulatory framework for maritime shipping, the regulatory framework for inland waterways shipping, the legal framework, the liability and insurance framework, the framework for certification and approval of operators and finally the classification society guidelines for MASS.

The gap analysis of the regulatory framework for maritime shipping (*SOLAS, CLL, TMC, STCW, COLREG, SAR, MLC, European Directives, National and Local regulations)* resulted in identification of 78 gaps or needs for amendments. Of these 78 gaps, 10% are categorised as high severity, 55% as moderate and 26% as low severity. Details on the gaps can be found in (Ahmed, et al., 2022) but examples of gaps that have been identified are:

- The meanings of “master”, “crew” and “responsible person” need to be clarified at different autonomy levels.
- Some instruments require manual operations, indication, or alarm on the bridge.
- Some instruments explicitly require the presence of humans on board, e.g., render assistance in a distress situation or pilotage requirements.
- The ways to transfer a “physical bridge” to an “electronic bridge” with detailed functionalities of an onboard control system, connectivity and remote control system are also needed to justify the equivalences of some proposed solutions to the existing instruments.

The gap analysis of the inland waterways regulatory framework (*RPNR, CEVNI, CLNI, CDNI, European Directives, Regional, National and Local regulations*) resulted in identification of 40 gaps or needs for amendments. Of these 40 gaps, 8% are categorised as high severity, 75% as moderate and 17% as low severity. Details on the gaps can be found in (Ahmed, et al., 2022).

Highly severe instruments may require longer time to get international acceptance. Therefore, a longer time frame needs to be set up to address these instruments. Alternatively, an exemption could be granted as a temporary solution, or a bi-lateral agreement could be signed among the contracting governments to allow the operation of MASS at its initial phase.

Moderately severe instruments mostly utilise trusted modern technologies to support the alternatives to comply with the existing instruments. Therefore, comparatively less time would be required to get their acceptance internationally or nationally if reliable technologies are used for implementing autonomous functions.

Last but not the least, the instruments that require definition or clarification wise amendment is relatively easy to get worldwide acceptance within a short period of time. These types of instruments could be prioritised to do the amendments in the early phase.

The gap analysis of the legal framework (*UNCLOS*) resulted in the identification of the following seven gaps:

- A proper definition of 'ships' / 'vessel' is needed.
- There is a lack of well-established rules or regulations for autonomous ships in flag state jurisdiction.
- The freedom of movement for autonomous ship can be limited due to lack of commonly agreed rules and regulations in port and coastal state jurisdiction.
- Autonomous ships' right of 'innocent passage' through other states' territorial seas is not defined in port and coastal state jurisdiction.
- Each ship needs to have a (properly qualified) master and a crew in port and coastal state jurisdiction.
- Every state shall require the master of a ship flying its flag and it is his obligation to render assistance to persons in danger or distress. (Also specified in SOLAS Regulation V/33).
- Every state shall require the master of a ship flying its flag and it is his obligation to render assistance to persons in danger or distress (Article 98(1)).

Note that the latter two rules might have a limited applicability in the context of autonomous ships in case of unmanned operations.

The gap analysis of the liability and insurance framework (*Merchant Shipping Act, the 1910 Collision Convention, The Hague and Hague-Visby rules, the 1976 Liability Limitation Convention, as well as other general and insurance relevant issues)* resulted in identification of 15 gaps. The most important identified gaps are:

- Increased liability exposure of shipowners and system suppliers
- Shifting in liabilities towards new players.
- Issues in determining the insurance pricing/coverage for new technologies.
- Liabilities issues: Strict liability vs. liability irrespective of fault.

Note that as liability and insurance issues are expected to be resolved faster than regulatory issues, they are not considered to be critical in terms of the timeline for large scale international autonomous shipping.

The gap analysis of the certification and approval of operators have resulted in identification of the following gaps:

- There is no agreed upon standard or process to approve and certify the quality of the RCC operator.
- There is no agreed upon standard or process to ensure the quality of the interactions between RCC operator, automation, and onboard crew.
- There is no agreed upon standard or process that can distinguish between the full range of tasks from direct control of a ship to supervision of a fleet and intervention when needed.

The gap analysis of the classification society guidelines resulted in identification of the following gaps:

- Lack of harmonisation between guidelines themselves and to some extent IMO MSC.1/Circ. 1455. and the guidelines.
- Lack of harmonisation between guidelines and recommended practices for assurance of new or novel technologies.
- Unstructured and imprecise descriptions of the MASS as there exists various definitions of the CONOPS and the information that is requested by the classification societies differs.
- Emphasis on preliminary design and analysis as opposed to detailed design,
- AI and ML is not adequately covered. Integration of these technologies must take into account that the performance of AI and ML models cannot be guaranteed in all situations and that these models may perform sub-optimal in unforeseen situations.
- Verification and testing of autonomous functions are either spread over a series of documents, or no clear process existing for this purpose.

11. DEVELOPMENT STATUS: THE COMMERCIAL INITIATIVES

While the impression from investigating the status of the main technology components is that they seem to approach TRL 9 in the short to medium term, it will be necessary with full scale testing in commercial operations to get there. So, what is the status in the market? Are there movers making the necessary investments? And considering the ongoing commercial initiatives, what gaps are of highest priority to close, and when do they need to be closed?

11.1. DEEP-SEA

It seems to be a consensus in the maritime industry that deep-sea shipping will be the last mover when it comes to unmanned, autonomous ships, but that deep-sea ships will take advantage of autonomous technologies to improve operations instead. Main arguments are that; deep-sea ships are typically large high value assets making it less likely that owners will take the risk involved in applying new technology at an early stage, that crew are needed for maintenance and interventions to secure the cargo, that crew costs make up a relatively small portion of the total costs, and that increased cargo capacity will be less significant because the superstructure takes up a relatively small portion of the ship space, making people believe that cost savings would be less significant than for e.g., shortsea shipping.

On the other hand, the insignificance of the cost saving is somewhat debatable because even though the cost saving would make up a smaller portion of the total cost, the total cost is significantly higher than for shortsea and IWW shipping, meaning that the absolute value of the cost savings could still be high. Furthermore, deep-sea typically includes long distance sailing where nothing happens and where autonomous navigation would be less complicated than for e.g., shortsea or inland waterways navigation. Deep-sea also typically involves few ports, and is often linear trade, which is an enabler for autonomous ships as it is believed that autonomous ships will require some customised infrastructure at the ports they visit. Another interesting theory is that autonomy may to some extent defeat the economy of scale, making it possible to build and operate smaller ships at the same transportation cost as for the mega ships of today. This would increase flexibility by splitting large shipments into smaller parts and by enabling more frequent departures and less complicated port side logistics. It would also increase resilience as the failure of one asset would have reduced consequence, and because disruptive global events such as pandemics would have less impact as the crew logistics crises that occurred in relation to COVID could be avoided. Finally, unmanned ships would move jobs to shore, which could answer the challenge related to recruitment of crew.

There are both arguments for why deep-sea shipping is and isn't a good candidate for unmanned autonomous shipping. Main obstacles seem to be related to maintenance and cargo integrity, and to stakeholder perception of advantages not outweighing disadvantages. To get some insight into when we can expect that autonomy is taken up in deep-sea shipping, we will therefore take a look at the ongoing initiatives and the current status within deep-sea shipping.

11.1.1. Ongoing commercial initiatives

In short, commercial initiatives for autonomy in deep-sea shipping are few and mostly focused on decision support for the onboard crew. There are some commercial technology demonstrators outside EU, and some have signed contracts for delivering their products to newbuilds.

In the APAC region, Korean Register (KR) will be closely collaborating with Hyundai Heavy Industries (HHI) and its subsidiary Avikus as well as the Liberian Registry (LISCR) to commercialise autonomous navigation technology. The four parties signed a Memorandum of Understanding (MoU) at HHI`s headquarters in Ulsan, Korea on the 26th of August 2022 to collaborate on bringing the Hyundai intelligent Navigation Assistant System (HiNAS 2.0) to market (Offshore Energy, 2022).

Avikus has been awarded a contract for delivering their HiNAS 2.0 system to 23 container and LNG ships owned by SK Shipping and Janggeum Merchant Marine (Offshore Energy, 2022). In addition, it is to be installed on a whale tour ship that is to be delivered in 2022, and to be become Korea's first autonomous large commercial vessel in 2023 (Avikus, 2022). The HiNAS 2.0 system is a Navigation Assistant System. It is a computer vision and AI-based system that assist safe navigation by displaying detected ships and navigation information in AR images. It can also create optimal routes and speeds, and it will be possible to use it to control the vessel steering commands in real time (Avikus, 2022) (CISION PR Newswire, 2022). Available information is limited, but it seems that the contracted deliveries to the 23 container and LNG ships are for operator decision support and not for autonomous control of ship navigation. The delivery to the whale tour ship, however, seems to be for autonomous control of the ship navigation.

The status seems to be that the HiNAS 2.0 is under development (Avikus, 2022), but that it has been tested in full scale in real operations (CISION PR Newswire, 2022). Furthermore, the American Bureau of Shipping (ABS) and the Korea Register of Shipping (KR) witnessed the 33-day 20,000 km trial, and ABS have issued certification for the HiNAS 2.0 (CISION PR Newswire, 2022). It thus seems that the HiNAS 2.0 is at TRL 8. It is, however, not clear if these first applications of the HiNAS 2.0 involves reduced crew or uncrewed navigation, as there is no mention of this in the reviewed articles. It is therefore assumed that the HiNAS 2.0 has reach TRL 8 as decision support to human operators.

Japan has launched some major initiatives, applicable to both deep-sea and shortsea vessels. NYK are developing their Sherpa System for Real ship (SSR), which is a navigation system for calculating optimal routes as decision support to the crew. The trials between the 14th and 17th of September 2019, and 19th to 20th of September 2019, monitored the performance of the SSR while it calculated collision risk, optimal routes and speeds and automatically navigated the ship (NYK Line, 2019). The trials established the technical and operational benefit feasibility and was a step towards realizing NYK's goal of crewed autonomous ships. NYK also believes that in time, the SSR can enable remote and unmanned navigation, answering crew shortage challenges. Available information is limited; however, it seems that the estimated TRL of the SSR is TRL5, considering that they state that they have proven feasibility, and considering that trials in a relevant environment has been conducted. It should be noted that this TRL estimate is for SSR as decision support. SSR as part of an autonomous ship with uncrewed navigation (supported by RCC) is not discussed in the available articles.

NYK is also a partner of the DFFAS (Designing the Future of Full Autonomous Shipping) consortium (NYK Line, 2020). Though DFFAS is relevant for deep-sea, at least in the long run, it is mainly a shortsea initiative and hence discussed in the section 11.2.

Another deep-sea related initiative is Sea Machines which has demonstrated remote navigation for a tugboat (gCaptain, 2021), and which has received approval in principle for the autonomous routine transit and stand-by operations, before trialling remote piloting from an RCC (Sea Machines, 2022). Since a tugboat is an important part of the deep-sea ship port operations, this initiative is one of several necessary steps for unmanned, autonomous commercial deep-sea operations. Sea Machines have a computer vision product AI-ris, and an autonomous command & control system called SM300 which is installed on the tug Rachael Allen, which has received ABS Approval (Sea Machines, 2022). They also seem to have a remote control station solution for RCCs, though limited details are available (Sea Machines, 2022), and they do have a Remote Helm Control System for line-of-sight wireless helm and propulsion control that is type approved by Bureau Veritas (Sea Machines, 2022)

Finally, the Rosmoport fleet owner has entered a contract with Sitronics for equipping two autonomous rail/vehicle carriers of about 200 meters (MARINET, page visited March 2023). The ships will get autonomy class by Register of Shipping and required crew number will be reduced.

Some of the actors do state that their products have the potential for enabling unmanned remotely controlled or autonomous ships, however, currently there are no concrete commercial initiatives targeting autonomous uncrewed or unmanned deep-sea freight transportation. It seems that decision support is on the horizon for the short term, potentially enabling some crew reduction, or concepts like periodically unattended bridge or periodically reduced crewing of the bridge in the medium to long term. However, RCC supported unmanned ships seem to be far into the future, and not likely before well into the long-term perspective

11.2. SHORTSEA

In contrast to deep-sea shipping, it seems to be generally accepted that shortsea shipping will be the first mover for unmanned, autonomous commercial shipping (in the form of shuttles operating in limited areas). Main arguments are that the crew cost is a significant portion of the total cost (e.g., the AUTOSHIP shortsea demonstrator where crew cost represented 36% of the total costs for 2021), removal of the superstructure and crew related equipment will give a significant increase in cargo capacity (Gribkovskaia, Borgen, Holte, Lindstad, & Nordahl, 2019) and might balance out additional autonomy related capital costs (Kretschmann & Burmeister, 2017), and that the removal of energy consuming equipment related to having crew onboard will give a significant reduction in fuel consumption (Allal, Mansouri, Youssfi, & Qbadou, 2018), (Kretschmann & Burmeister, 2017). Another key difference between shortsea and deep-sea shipping is that time between ports in shortsea is shorter, making it more realistic that maintenance and repairs can be done while at port, and that the ships can manage the distances without such interventions.

Opportunities are also seen in new logistical concepts, such as mother daughter concepts where mother ships perform the longer transportation legs, and small daughter ships do the distribution to smaller ports in networks connected to larger terminals visited by mother ships (Akbar, et al., 2021) and (Msakni, et al., 2020).

It also appears to be generally accepted that unmanned, autonomous ships will first find their applications in liner trades. This is related to the fact that it is believed that autonomous ships will depend on dedicated infrastructure in the ports they visit, boarding teams for maintenance and service, and that it cannot be expected that any random port can accommodate an autonomous ship for quite some time to come.

11.2.1. Ongoing commercial initiatives

There are several ongoing commercial initiatives for remotely controlled and unmanned, autonomous commercial shipping in shortsea shipping. A common denominator is that these initiatives target reduced or zero emissions, that replacing truck transportation is central, that the ships are applied in liner trade, and that a stepwise approach towards autonomous shipping via crewed, and later uncrewed, remotely controlled ships, is planned. This means that the ships are built with a bridge and that initial operations will be with an onboard crew. Thus, the ships will not reap all benefits from unmanned shipping initially, however, plans for removing the superstructure and crew related systems are in place for some of the initiatives. These initiatives are very important steps as they will provide valuable experience and knowledge, both within technology, regulations and approval, and operations, paving the way for the next generation ships.

Norway and Northern Europe are at the forefront of the developments within autonomous freight vessel services with three autonomous shuttles already built and delivered to the cargo owners Yara and ASKO. Both ASKO's two autonomous ferries and the Yara Birkeland are already in commercial crewed operation and have a target of unmanned autonomous commercial operation by the end of 2024 (FleetMon, 2022) (Kongsberg Maritime, 2022). These three ships are all electric and have received considerable funding through ENOVA (Enova, 2022) grants for reducing CO_2 emissions by replacing truck transportation with zero-emission ships. Another commonality for these three ships is that Kongsberg Maritime and Massterly are respectively technology providers and operators. These companies are therefore leading the race to supply the Key Enabling Technology (KET) and services to autonomous shortsea transportation ships.

Another two ships are in the pipeline as Samskip has partnered with Ocean Infinity and secured funds to build two 500TEU hydrogen-powered, remotely controlled, and autonomous-ready containerships for delivery by 2025 (SamSKIP, 2022). They have received a 15mEUR grant from ENOVA to build the ships that will operate between the Oslo Fjord and Rotterdam. Details on intended manning level, or degree of autonomy, are not available, however it appears that the technology development is a required part of the project (Ocean Infinity, 2022), though the construction contract is already awarded to Indian shipyard Cochin Shipyard Ltd. (Samskip, 2023).

One zero-emission autonomous shortsea container ship was announced as DB Schenker, Ekornes, Naval Dynamics, Kongsberg Maritime and Massterly, have signed a pre-study agreement (Kongsberg Maritime, 2022). The ship is intended to operate in the dedicated supply chain for the cargo owner Ekornes, and will be of the NDS AutoBarge design, which is the same design used by ASKO. While the timeline for design, construction and operation is not known, this is yet another commercial initiative employing autonomy to achieve unmanned shortsea transportation.

Finally, one zero-emission autonomous shortsea container ship is under development for shipowner Zulu Associates (Vlaandern verbeelding werkt, 2022). The initiative is called ZULU MASS and is a 100-meter-long shortsea container ship with a 200 TEU capacity. Designed to operated uncrewed and zero-emission in the North Sea and English Channel. The ship design has received approval in principle from Lloyd's Register (Lloyd`s Register, 2022), indicating that the design has a good chance of meeting all regulatory criteria for certification.

There is also a major initiative in Japan called *Designing the Future of Full Autonomous Ship (DFFAS)* targeting unmanned shortsea freight by 2025. DFFAS is a consortium participating in the Joint Technological Development Programme for the Demonstration of Fully Autonomous Ships, under the fully autonomous ship project "MEGURI 2040" (The Nippon Foundation, 2022), launched by The Nippon Foundation in February 2020. MEGURI 2040 aims at transforming 50% of the Japanese fleet to autonomous within 2040. From February 26th to March 1st 2022, the DFFAS consortium conducted a successful trial simulating the actual operation of a fully autonomous[11] ship Suzaku by having the vessel sail a distance of approximately 790 kilometres between Tokyo Bay and Ise Bay, including offshore manoeuvring, bay navigation, coastal navigation, and berthing manoeuvring, using a comprehensive fully autonomous navigation system (DFFAS system) (NYK Line, 2022). The ship was operated autonomously with crew onboard in case of an emergency, and with support from an RCC. We have not found details on the KETs used in this trail, or what "simulating" means. This makes it hard to estimate the TRL of the involved technology, however the scale of the trial and the available information indicates that they might be at around TRL 5, or possible 6, at least for some KETs. Another "world-first" trial by the MEGURI2040 project is the trial where Mitsubishi Shipbuilding and Shin Nihonkai Ferry completed the demonstration of a fully autonomous ship navigation system on a 222-meter RoPax ferry, Soleil, in Kyushu Japan. The MEGURI2040 company NYK and its group companies MTI Co., Ltd., and Japan Maritime Since Inc. is also developing a framework for a fully autonomous ship called APExS-auto. The APExS-auto framework received an Approval in Principle by Bureay Veritas in March 2022 (Bureau Veritas, 2022). The framework is an acronym for Action Planning and Execution System for Full Autonomous (NYK, 2022).There are also some commercial initiatives not targeting transportation, but which could be said to operate in the shortsea segment. Ocean Infinity has placed contracts for the construction of several robotic vessels. The vessels are of four main designs of different lengths: 21m, 36m, 78m and 85m, intended for offshore data acquisition and intervention (Offshore Energy, 2022). Details on the project, intended autonomy level and status, is scarce, however, it appears that the smaller two designs are intended for unmanned operations only, while the larger two appears to have conventional bridges and living quarters and are said to be optionally crewed (Ocean Infinity, 2022). Their remote control centre is live, though it is not in commercial operation, and the Armada fleet concept is in the trial stage (Ocean Infinity, 2022) (Offshore Energy, 2022).

Another initiative that has been launched is that of Reach Subsea, Reach Remote (Reach Subsea, 2022). Reach Remote will build unmanned offshore service vessels for subsea services. The ships will be approximately 25 meters, equipped with ROVs, and will be unmanned. The ships will be equipped with Kongsberg Maritime technology and will be supported from an RCC operated by Massterly. There will be no accommodations for crew onboard the ships, which is exploited to design significantly smaller subsea services ships than what is possible today. Details on the project, intended autonomy level and status, is scarce. However, the first two ships are planned to be delivered in mid-2023 (Reach Subsea, 2022).

Though the Armada fleet and the Reach Remote ships are not intended for transportation, the ships and technology are relevant for shortsea transportation because several challenges related to operational

[11] The MEGURI definition of fully autonomous does not correspond to the definition in section 3.1 as their autonomous ship concept includes an RCC intended to intervene in case the autonomous ship cannot resolve the situation. This is more in line with Constrained Autonomy (CA).

conditions, tasks such as navigation and obtaining situational awareness, RCCs, and required technology, are similar. In fact, the technology providers and RCC operators for both these initiatives are also involved in the discussed autonomous shortsea transportation projects, so knowledge and experience from the Armada and Reach Remote projects will contribute to the developments within autonomous shortsea shipping. Both projects also exploit the possibilities to re-design ships completely due to having no crew. This is clearly seen by the significantly smaller ship-designs compared to conventional ships that performs the same operations. Reach Subsea estimates a significant cost reduction, both for the initial investment, and for the operations cost (Reach Subsea, 2022), while the reduction in emissions compared to current large and crewed ships is estimated to 90-100% (Reach Subsea, 2022). This could also provide valuable experience for the design of autonomous cargo ships.

Another relevant initiative, somewhat similar to the Armanda and Reach Remote ships, is the already built Zhu Hai Yun. China has put the unmanned drone carrier research ship Zhu Hai Yun into operation, and the 88.5 meter ship can carry unmanned air, sea and submarine drones, and can perform marine survey tasks such as ocean surveying, mapping and observation, sea patrol and sampling (Global Times, 2023). It has also received the first intelligent ship certificate by the China Classification Society and is capable of autonomous navigation in open water and remote control (Global Times, 2023). Though it is not stated in the available articles, the remote control capability indicates that an operational RCC is also in operation.

In France, SeaOwl has demonstrated remote operation from Paris of the retrofitted offshore supply ship VN Rebel, navigating from the Mediterranean port of Toulon (Bureau Veritas, 2020): *Bureau Veritas provided a reference framework, and risk analysis - based on its own guidance for autonomous shipping (NI 641), to develop a means for the French maritime administration to approve the ROSS concept as per IMO MSC.1/Circ. 1455 for alternative designs.* In late 2021 SeaOwl received its first InSPEAR vessel (Innovative Nautical Safety & Protection by Enhanced Autonomous Reconnaissance), which is a 10 meter vessel for offshore surveillance and protection, and which is to be remotely or autonomously controlled from an RCC (SeaOwl, 2022).There are also several smaller survey units, falling into the category USVs, that are in commercial operations. Some examples: In 2021, Bureau Veritas delivered Approval in principle to DriX, an USV by iXblue, designed to perform hydrographic and geophysical surveys, water column analysis and subsea positioning operations (Bureau Veritas, 2021). The USV is designed to operate autonomously, and to be remotely controlled. In 2022, Jan DeNul Group ordered the Maritime Robotics Mariner class USV for autonomous offshore survey operations (Maritime Robotics, 2022), and Van Oord placed an order for a 6 meter autonomous USV by Demcon unmanned systems, for offshore inspection.

Trafikverket Sweden has signed a contract with Holland Shipyards Group for the delivery of two plus two autonomous, crewed, all-electric ferries (SMASH!, 2022). The contract also includes auto-mooring systems and an RCC. The ferries will be controlled from the RCC based in Stockholm and operating on IMO autonomy level 2 (IMO, 2021); the vessels are remotely monitored but do have crew onboard that can take control if needed (SMASH!, 2022). Another autonomous ferry initiative is the Bastø VI, which is already operating on a regular route and is equipped for autonomous transit and automatic docking (Norwegain Maritime Authority, 2022). Collision risks are detected by the system and alerted to the captain who then takes over control (Kongsberg Maritime, 2020). Though these commercial initiatives are for vehicle and passenger transport, they provide valuable experience from real life application of autonomous technology that is relevant for autonomous Navigation, docking, and shortsea ro-ro cargo ships.Since RCCs are expected to be an important part of autonomous ship systems for the foreseeable future, it is worth noting that both Massterly and Ocean Infinity (and probably China) have opened their first RCCs. With limited information on some of the initiatives, it is hard to determine if other RCCs are operational, though this seems likely. Furthermore, Massterly is already in the commercial operation phase for the Yara Birkeland, while several others have conducted the first demonstrations of remote operations. This shows that RCCs are slowly appearing, which is crucial for the uptake of autonomous ships, though it seems that only Massterly is currently targeting “RCC as a service” as a business model for the maritime segment.

Given the ongoing initiatives, it appears that commercial autonomous sheltered waters shortsea shuttles, operating in relatively small areas within one nation, are emerging within the short-term perspective. Autonomous ships in un-sheltered waters operating in larger areas, including international voyages, are a bit further down the line. One ship has received approval in principle (but no timeline for construction and entering operation is public), and one ship is funded and announced as “autonomous ready”. Autonomous ships in international waters also depends on international legislation and will take a longer time to get approval for, they will have to deal with higher navigational complexity, and it is more complicated to ensure operability due to maintenance issues. Developments within shortsea can therefore be divided into national and international operations, where autonomous ships will appear first in national operations, and later in international operations. It is also likely that autonomy in international operations will first appear in crewed ships in the form of partially uncrewed (PU) ships which means that the bridge can be uncrewed in periods, such as during transit, while there are always crew onboard for taking over control for more complicated situations. With this in mind, commercial autonomous ships in national shortsea operations will appear in the short term, while autonomous ships in international shortsea operations will appear in the medium to long term.

The shortsea initiatives are important steps towards international and intercontinental autonomous shipping; three projects will result in autonomous regional sheltered water transportation, while one will result in autonomous international shipping. Furthermore, the sheltered waters initiatives deal with transportation chains and cargo that could be connected to the initiative for the international transportation chain. The initiatives also solve transportation problems that are transferrable to other regions and supply chains. In addition, the non-transport related initiatives contribute to the technology development, increased knowledge, and experience from autonomous ship operations, and as such the developments towards large scale autonomous shipping.

11.3. INLAND WATERWAYS

While shortsea is expected to be the first mover for unmanned commercial shipping, there is also a significant interest in autonomous unmanned shipping in inland waterways. Inland Waterways is strategic for EU, since it is a great resource to move goods from road to water in a large area of Europe, from West to East. There are however few studies on ship concepts and business cases that are competitive to truck transport, with a few exceptions where it is found that autonomy has the potential to improve competitiveness of IWW shipping (Peeters, et al., 2020), (Meersman, et al., 2020), and (PNO, USTRAT, STF, ZA, & EAS, 2023). Furthermore, (Meersman, et al., 2020) also finds that smaller vessel types have less benefits of autonomy, and for some routes and vessel combinations that costs would increase.

The lack of studies means that the business case is more uncertain than for shortsea shipping. As an example, inland waterways vessels typically have smaller crews than ocean going vessels, which makes the potential cost saving smaller. However, other benefits from autonomy, like increased cargo capacity and the possibility to extend the operational times beyond the 16 hours a day that are normal for many IWW ships, could lead to increased competitiveness. How these factors balance out is somewhat uncertain, though one such study is found in AUTOSHIP deliverable D7.3 (AUTOSHIP, 2023) where it is found that the competitiveness is increased by autonomy for both the IWW and SSS cases, both through reduced overall costs and reduced external costs.

On the technology side, much can be transferred from the advancements within shortsea shipping. Though, navigation is likely more complicated due to hydrodynamic effects from interactions with the waterways and other ships, which means control algorithms dedicated for inland navigation are needed. However, the AUTOSHIP project have addressed this in the KET development, which means that solutions are on the horizon. Furthermore, while unmanned shortsea ships must find new solutions for maintenance, like establishing teams for boarding the ship while it is at quay, inland waterways ships are always closer to a quay and many already perform maintenance and service by boarding crews. This means that challenges related to maintenance are less of a problem for inland ships than for shortsea and certainly deep-sea ships.

11.3.1. Ongoing commercial initiatives

The technology and service provider SEAFAR have already made semi-autonomous crewed sailing a reality by controlling ten ships from a control room in Antwerp and is planning similar facilities in Namur and Dordrecht (SEAFAR, 2022). Since March 2021, SEAFAR has received additional permission to operate at night and test without crew onboard, but with control from an RCC (CCNR, 2022). SEAFAR`s captain directs ships remotely from a control room. They steer up to three ships at a time, and it is stated that (SEAFAR, 2022) “80% goes autonomous, with only a few crew remaining on board”. It is assumed that this statement means that 80% of operations are performed autonomously. SEAFAR has a partnership with Alewijnse which is a system integrator and which (SEAFAR, 2022) "…offers a comprehensive package of technical solutions that includes full electrical installations, systems for energy distribution, generation and propulsion, process automation, audio, video & ICT and systems for safety, navigation and communication.".

Zulu Associates (Zulu Associates, 2022), a partner in the AUTOSHIP project, is acting as an initiator, developer, and operator of innovative vessels in marine and inland waterways logistic chains. Their goal is to enable zero emission operation of commercial vessels on inland waterways, shortsea and coastal routes through autonomous operation and alternative propulsion. Zulu Associates is developing an autonomous barge with low to zero-emission propulsion for navigation on European inland waters. The barge is called the X-Barge and is a CEMT class 4 barge. The aim is to prove that this type of vessel can operate on the Rhine in 2023 and to obtain the permit for permanent uncrewed commercial operation.

The commercial initiatives related to inland waterways appears to be fewer than for shortsea, however, the ambitions related to autonomous technology seems to be the same, unmanned operations within a relatively short timeframe. As with shortsea, there is already one RCC in operation, and there is one commercial initiative targeting unmanned operations within the next few years. Legislation is, however, less complicated for IWW than for international shortsea. This may enable faster developments within inland waterways, and with this in mind, it appears that though IWW is a few years behind shortsea, we will see that commercial unmanned, autonomous IWW shipping is emerging within the short to medium term perspective, and probably that uptake of autonomous ships will be faster in IWW than SSS.

As for shortsea shipping, the ongoing commercial initiatives are also important steps towards international and intercontinental autonomous shipping; the X-barge project will result in autonomous regional transportation, and the RCC of SEAFAR will generate knowledge and experience not obtainable for the shortsea initiatives. Furthermore, the X-barge will be a part of transportation chains and transport cargo that could be connected to the shortsea initiative for the international transportation chain. The initiatives also solve transportation problems that are transferrable to other regions and supply chains. Combining the initiatives for IWW and shortsea, could make it possible to construct autonomous international waterborne transportation chains, e.g., stretching from Norwegian fjords into inland Europe. In addition, the IWW initiatives also contribute to the technology development, increased knowledge, and experience from autonomous ship operations, and as such the developments towards large scale autonomous shipping.

11.4. SUMMARY OF STATUS

Form the ongoing commercial initiatives it seems likely that the first ships in commercial unmanned autonomous operations will be within the shortsea segment (national sheltered water shuttles). This is because the required investments have already been made in the shortsea initiatives and because ships intended for autonomous commercial operations in shortsea have already been built. Current plans for some of the shortsea initiatives are to go unmanned within the end of 2024. Though it remains to see if this will be achieved, it seems that unmanned autonomous commercial operations in national sheltered shortsea is likely in the short term.

Developments within shortsea can be divided into national and international operations due to regulatory challenges, the complexity of operations, and in some case maintenance issues. We believe that autonomous ships will appear first in national operations, and later in international operations. It is also likely that autonomy in international operations will first appear in crewed ships in the form of Periodically Unattended bridge ships (PU) which means that the bridge can be uncrewed in periods, such as during transit, while there are always crew onboard for taking over control for more complicated situations. Therefore, while commercial autonomous ships in national shortsea operations will appear in the short term, autonomous ships (PU and uncrewed) in international shortsea operations will likely not appear until the medium to long term.

It also seems likely that the next segment where we will see unmanned, autonomous commercial operations is within inland waterways. There is one mover who has established an RCC that is already in operation supporting remotely controlled ships in commercial trade, some of which with reduced manning, and there are concrete plans for building the first IWW ship intended for autonomous commercial operations. Taking into consideration that the construction of the first unmanned autonomous IWW vessel is not yet started, we find it likely that unmanned autonomous commercial operations in IWW will appear in the short to medium term. However, the large-scale uptake of autonomy in IWW will likely be faster due to a less complicated legislative picture. While international shortsea operations depend on international legislation, IWW depends on legislation from a few nations, or perhaps the EU. In addition, maintenance will be more of a challenge for international, or medium to long distance shortsea shipping, than for inland waterways shipping.

The last segment where we will see autonomous commercial operations is the deep-sea segment. Though, as discussed, there are benefits that can be reaped also for this segment, the current commercial initiatives seem to focus on using the technology for improving manned operations. From what we have found in our investigations, there are no current commercial initiatives for autonomous[12] commercial deep-sea operations. Partially manned, and periodically unattended bridge concepts are likely the first steps that we will see, while autonomous commercial operations seem to be likely to appear first in the long term. This means that intercontinental large scale autonomous shipping is still far into the future.

[12] Recall our definition of autonomous ships as being unmanned constrained autonomous (see section 4.2 for details)

For international autonomous commercial shipping, in specific transport chains, there are however some developments within shortsea and IWW shipping that are preparing the ground. Though there are no concrete initiatives for an autonomous international supply chain, the building blocks for a network stretching e.g., from Norway, via a port such as Antwerp or Rotterdam to inland waterways, are starting to materialise. With this in mind, international autonomous commercial shipping could possibly be seen in the medium to long term time perspective.

12. CONCLUSIONS

12.1. GROUPING GAPS INTO MAIN THEMES (CONSTRAINTS)

When we go into the details of each PESTLE element and study gaps, we find that there are too many gaps to discuss all of them and place them on a timeline. Instead, we will define the main themes that can be considered constraints preventing the next development step, discuss in what order these should be addressed, and then propose a timeline (which is found in section 3).

Technology related gaps as seen from after the AUTOSHIP project were discussed in section 9. To group these gaps and make some prioritisations, we can sort them with respect to the main technological development step that they must be closed to achieve, and in technology categories that have common properties for each technological development step.

Starting with the technological development steps we will use the autonomy levels AO, RC, CA and FA, as defined in (Rødseth, Wennersberg, & Nordahl, 2022) and given in section 9.7, as the main technological development steps. In addition, we expect the standardisation of the autonomous ship – RCC interface to be a significant step as it will open for moving autonomous ships between RCCs, which opens the second-hand market and thus considerably improves the business case for investing in autonomous ships. We call this *CA standard RCC*.

Next, the main technology categories are *Autonomous navigation* which includes the KETs ANS and SA, the *RCC,* the *Safety and automation system* which includes the KET IMS, *Maintenance, Port call interface* which are the functions related to a port call that no longer can be performed by the crew.

Finally, we can group gaps as given in tables: Table 4, Table 5, Table 6, Table 7 and Table 8.

Table 4 Autonomous navigation gaps per development step

Technology development step	Gaps
AO	None
RC	Automation must support remote control and redundancy
CA	Automation must enable autonomous navigation under defined conditions and the ANS must be able to detect when a handover to crew is required
CA standard RCC	Same as previous, and requires standards for RCC-autonomous ship interface
FA	Internationally accepted rules for interactions (e.g., COLREGs) are required and must be implemented. Automation must handle the full operational envelope

Table 5 RCC gaps per development step

Technology development step	Gaps
AO	None
RC	Must support remote control and redundancy
CA	Operator-automation responsibility model is needed
CA standard RCC	Same as previous, and requires standards for RCC-autonomous ship interface and responsibility model
FA	No additional gaps

Table 6 Safety and automation systems

Technology development step	Gaps
AO	None
RC	IMS and predictive maintenance needed, automation needs redundancy support when relevant
CA	IMS must be more advanced and able to predict system performance based on component failures, and capable of providing ship situational awareness as input to the ANS. All automation systems related to SAS must be at least constrained autonomous
CA standard RCC	Same as previous, and requires standards for RCC-autonomous ship interface
FA	Automation must handle the full operational envelope

Table 7 Maintenance

Technology development step	Gaps
AO	None
RC	Need methods for predicting time to failure and maintenance need, new maintenance schemes to ensure operability for unmanned operations, required maintenance frequency must be reduced meaning less maintenance intensive solutions are needed
CA	No additional gaps
CA standard RCC	No additional gaps
FA	No additional gaps

Table 8 Port call interface

Technology development step	Gaps
AO	None
RC	Container lashing and securing cannot be done without manual labour Automatic gripping of various cargo types is not solved Situational awareness for cargo handling is mostly non-existing - detecting the gripping points, finding the drop-off locations, detecting obstacles and persons. Collision avoidance in the general case must be solved. Based on SA, make safe decisions such as replan the path for the crane movements, freeze movements, lower cargo, or go to a safe position, etc. Digitised and automated stowage planning, or bay planning, – based on a cargo loading plan, the current ship status (such as current cargo onboard, stability issues, etc.), cargo delivery plan, and possible special concerns for the cargo, algorithms for generating optimal placements of cargo, loading sequences, etc. Digitised and automated logistics planning based on current cargo position and status in the logistic chain, destination, and available candidate transport vessels and vehicles.
CA	No additional gaps
CA standard RCC	No additional gaps
FA	No additional gaps

While some gaps can be grouped and sorted in terms of when they must be solved to enable technological development steps, we have some gaps which can be considered constraints that needs to be removed to make it possible to exploit the technological development steps to create and put autonomous ship concepts into operation. These can be grouped into the main categories *Regulation* (or legal), *Standards*, *Business models*, *Economy*, *Societal acceptance*, and *Policy actions*.

Legal gaps were discussed in section 10. Since the number of gaps related to legal aspects are high, we have grouped them as shown in Table 9. Note that as liability and insurance issues are expected to be resolved faster than regulatory issues, they are not considered to be critical in terms of the timeline for large scale international autonomous shipping.

Table 9 - Legal, liability and regulatory gaps.

Gap Groups	Gaps
Today's legislation	• Lack of harmonisation between guidelines themselves and to some extent IMO MSC.1/Circ. 1455. and the guidelines. • Lack of harmonisation between guidelines and recommended practices for assurance of new or novel technologies. • Unstructured and imprecise descriptions of the MASS as there exists various definitions of the CONOPS and the information that is requested by the classification societies differs. • Emphasis on preliminary design and analysis as opposed to detailed design, • AI and ML is not adequately covered. Integration of these technologies must take into account that the performance of AI and ML models cannot be guaranteed in all situations and that these models may perform sub-optimal in unforeseen situations. • Verification and testing of autonomous functions are either spread over a series of documents, or no clear process existing for this purpose.
National permit	For high severity gaps, an exemption or permit could be granted as a temporary solution until rules and regulations are in place on EU level for IWW and possibly maritime shipping, and international level for maritime shipping
National legislation	Each country will have to develop or adapt national regulations to progress to avoid issuing permits or exemptions while the use of highly automated ships is increasing.
Use of IMO Guidelines	According to IMO MSC 106 roadmap the voluntary guidelines for risk based approval of MASS will be finished in 2024. This should give a more harmonised and possibly structured approach to approval by national authorities. Voluntary guidelines may also solve the sometimes-quoted problem that UNCLOS will not allow operation of uncrewed ships in international waters unless suitable IMO instruments have been developed to allow it.

Gap Groups	Gaps
International legislation	78 gaps in *SOLAS, CLL, TMC, STCW, COLREG, SAR, MLC, European Directives, National and Local regulations,* where 10% are categorised as high severity, 55% as moderate and 26% as low severity: • The meanings of "master", "crew" and "responsible person" need to be clarified at different autonomy levels. • Some instruments require manual operations, indication, or alarm on the bridge. • Some instruments explicitly require the presence of humans on board, e.g., render assistance in a distress situation or pilotage requirements. • The ways to transfer a "physical bridge" to an "electronic bridge" with detailed functionalities of an onboard control system, connectivity and remote control system are also needed to justify the equivalences of some proposed solutions to the existing instruments. 7 gaps in UNCLOS: • A proper definition of 'ships' / 'vessel' is needed. • There is a lack of well-established rules or regulations for autonomous ships in flag state jurisdiction. • The freedom of movement for autonomous ship can be limited due to lack of commonly agreed rules and regulations in port and coastal state jurisdiction. • Autonomous ships' right of 'innocent passage' through other states' territorial seas is not defined in port and coastal state jurisdiction. • Each ship needs to have a (properly qualified) master and a crew in port and coastal state jurisdiction. • Every state shall require the master of a ship flying its flag and it is his obligation to render assistance to persons in danger or distress. (Also specified in SOLAS Regulation V/33). • every state shall require the master of a ship flying its flag and it is his obligation to render assistance to persons in danger or distress (Article 98(1)). Certification and approval of operators • There is no agreed upon standard or process to approve and certify the quality of the RCC operator. • There is no agreed upon standard or process to ensure the quality of the interactions between RCC operator, automation and onboard crew.

Gap Groups	Gaps
	• There is no agreed upon standard or process that can distinguish between the full range of tasks from direct control of a ship to supervision of a fleet and intervention when needed. Liability: • Increased liability exposure of shipowners and system suppliers • Shifting in liabilities towards new players. • Issues in determining the insurance pricing/coverage for new technologies. • Liabilities issues: Strict liability vs. liability irrespective of fault. According to the latest roadmap for development of a MASS code in IMO (IMO MSC 106 report), a mandatory code will be available in 2025 and is planned to be adopted in 2026 and will then enter into force in 2028. In principle, one should expect this code to close the gaps in the IMO instruments.
EU legislation	40 gaps in RPNR, CEVNI, CLNI, CDNI, European Directives, Regional, National and Local regulations where 8% are categorised as high severity, 75% as moderate and 17% as low severity. For high severity gaps, an exemption could be granted as a temporary solution, or a bi-lateral agreement could be signed among the contracting governments to allow the operation of MASS at its initial phase.
COLREG updated	The current development of guidelines and eventual code for MASS in IMO explicitly states that this development shall have no implication for conventional ships, i.e. MASS needs to interact with conventional ships based on the existing COLREG. COLREG works well for human mariners that have a great deal of flexibility in how the COLREG rules are applied in more complex scenarios that cannot be resolved by the basic rules. This may, however, be a problem for an automated navigation system as computers are notoriously bad at guessing what humans will do in more complex situations. It may be possible to overcome this by implementing very cautious routines for interaction, but this will reduce efficiency. The best approach may be to use the RCC operator to assist in the situations where COLREG cannot be directly applied, rule by rule. This would rule out full autonomous operation. However, in the future when IMO has more experience with MASS, the organization may be more willing to look at alternative arrangements where more information is exchanged between ships to make interactions safer, also for conventional ships. This could be implemented as a new service on the proposed VHF Data Exchange

Gap Groups	Gaps
	System (VDES). This will probably require an amendment to COLREG to become effective. These issues are discussed in more detail in (Rødseth, Wennersberg, & Nordahl, 2021).

The identified gaps related to standards are already at a quite high level, so no further grouping is needed:

- New process and documentation standards to simplify and improve the validation and assurance process for KETs and related functions that currently do not have performance standards.
- Interoperability standards covering the interfaces and information exchange between KETs
- Performance and test standards for KETs
- Integration test standards for autonomous ship systems
- Interoperability standards for Ship-RCC, Ship-Ship, and Ship to shore-based stakeholders.

The gaps related to business models are also at a high level and the problem is that for autonomous ships, being at such an early stage, there are virtually no commercially established proven business models. On a high level, the gaps are:

- Missing business models for owning and operating autonomous ships (traditional ship owners? Cargo owners become ship owners? Technology provider owns ship and offers transport as a service?)
- Missing business models for providing services to autonomous ships, such as based on sharing resources like RCCs, infrastructure, and maintenance teams, etc.
- Initially, business models are likely dependent on financial support to be economically sustainable. E.g., autonomous ship service providers will have a very limited market, but the market cannot grow if the services are not available.

Gaps related to economy are also at a high level and no further grouping is needed:

- Lack of knowledge about when and where autonomous ships are applicable, and how the cost and emissions can be quantified creates uncertainties
- Lack of infrastructure and port services for autonomous ships, and this is too expensive to finance for the ship-owner.
- No standards for the technology, the autonomous ship system, and the approval process makes the approval process costly
- Initial autonomous ships will be custom made with proprietary solutions such as interfaces towards RCCs, meaning the second-hand market will be nonexciting.
- Internationally in general, externalities are not internalised

- Lack of funding schemes targeting early movers and the establishment of infrastructure and services supporting autonomous ships

Closing the gaps related to regulation, standards, business models and economy, can be facilitated by developing a strategy for policy actions intended to remove constraints and accelerate uptake of autonomy. The following gaps related to policy actions were identified, and these also do not need further grouping:

- To stimulate investments in new green and autonomous technology-based ships, there is a need for international (e.g., EU) policies that internalise external costs (societal costs) by funding investments that reduce external costs, such as the ENOVA program.
- Establishing infrastructure, such as RCCs and required infrastructure in ports, will require funding through policies. Infrastructure investments will first pay-off when a sufficient user-base is in place, while the user-base cannot grow without the infrastructure in place. Initial investments to accelerate the developments to a level where autonomous ship operations are self-sustainable are needed. International (e.g., EU) policies to provide grants to such investments are needed.
- New technological solutions related to infrastructure services are needed to support autonomous ships. These must be researched and developed, before they can be invested in and built. Policy actions to attract infrastructure service providers to participate in research and development and innovation projects are needed. Possibly through calls targeting these stakeholders.
- International (e.g., EU) policies that internalise external costs through fees or taxation schemes are needed.
- New international (e.g., EU) regulations or technical requirements intended to stimulate the transition to autonomous solutions, within a given timeframe, may also be needed to accelerate uptake of autonomy
- We also recommend that policy programs for funding R&D continues, as they are still needed. Depending on the maturity of each R&D topic and technology, a transition from RIA to IA will at some point be needed.

A prerequisite for a political environment that is motivated for accelerating the uptake of autonomy is societal acceptance. The identified gaps related to societal acceptance are also at a high level and do not need further grouping:

- Dissemination of societal benefits such that the public (and wider stakeholder) acceptance is ensured
- Make agreements with unions ensuring the future of workers while autonomous ship operations are ensured, also in terms of economy.
- Make the public aware of recruitment challenges, and the future deficit of the workforce.
- Educate stakeholders, such as investors, customers, and operators, and establish trust.

12.2. GAP GROUP PRIORITIZATION (CONCLUSION)

The end goal of this work is to create a high-level roadmap for the realisation of large-scale intercontinental autonomous maritime logistics. Based on the scope of this roadmap, and the discussions in the previous sections, we have identified four main segments that are important components of the large-scale intercontinental logistic chain: Inland waterways, sheltered water shuttles, shortsea (international and national long distance), and deep-sea. So, the high-level roadmap for realisation will be a summary of how these four segments will develop over the next 30 years in steps of 5-year periods. Starting with the period up until 2025 and ending with the period from 2045-2050.

The high-level roadmap indicates the type of ship concepts that we believe will be realisable in the given period, within each segment. It also includes the relevant technological development step and main constraining factor, for each segment in each period. The high-level roadmap and discussions related to each realisation step are given in section 3.3.

The technological development steps and constraining factors are basically the gap groups identified in the previous section. So, the prioritization of these is based on what gaps need to be closed to enable the realisation of the given ship concept on the given segment at the given time. The sequence of the technological development steps is given by the natural evolution of the technology (each step builds on the previous), this is discussed in more detail and presented in section 3.1.

Finally, the constraining factors and when they need to be removed, as well as some proposals on how policies play an important role in removing them, is discussed in section 3.4. These are also presented as a road map following the timeline of the high-level realisation roadmap in section 3.3.

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14. APPENDIX A: ROADMAP SURVEY RESULTS

A draft version of the roadmap was circulated in February 2023, along with a survey to collect feedback and rating of the predictions, identified constraints, and proposed policy actions. In addition, the roadmap was presented to the AUTOSHIP and AEGIS strategic advisory boards on the 17th of February. The survey with all results is found in section14.4, while sections 14.1-14.3 provides the highlights of the results and a brief discussion.

The number of responses (15) was a bit low, which means that details are note easy to extract since one answer can have a high impact on the average. As an example, the stakeholder category was included with the goal of evaluating the differences in views within different categories. Such an evaluation could not be done due to too few participants per category. However, the results did provide feedback leading to improvements. Furthermore, since this is a roadmap, differences in opinions are expected. With that in mind, the observed general trend in the responses being above average for all survey questions (i.e., more in agreement than in disagreement with our proposals) shows that most find our reflections and proposals reasonable.

The following will discuss the results in some more detail.

14.1. HIGH-LEVEL ROADMAP SURVEY RESULTS

One interesting observation during the discussions of the roadmap with the strategic advisory groups was that one meeting participant expressed that the roadmap timeline is too ambitious, while another expressed that it is not ambitious enough and that targets will be achieved quicker than what we indicate. If we look to the survey results for the evaluation of the high-level roadmap, we find that the general trend is that respondents tend to find our targets feasible or likely, with average scores from 3.47 to 4 for the different periods[13]. As seen from the results in section 14.4 (summarised in Table 10) only 2% of answers to all questions related to the high-level roadmap are that the targets are “highly unlikely”, only 7% are “unlikely”, 33% are “50/50”, while 41% are “likely”, and 17% are “highly likely”. Which shows that the high-level roadmap is mostly considered likely achievable by the respondents.

[13] A score of 1 means that the respondent finds the probability of achieving the targets for the specific period to be “highly unlikely”, 3 means “50/50”, while a score of 5 means “highly likely”.

Table 10 Summary of ratings for the high-level roadmap

	Number of answers per rating per question						Totals per rating level	
	Q4	Q5	Q6	Q7	Q8	Q9	Number	Percent
5 – Highly likely	3	2	2	3	2	3	15	17%
4 – Likely	9	7	5	5	6	5	37	41%
3 - 50/50	3	5	6	4	6	6	30	33%
2 – Unlikely	0	1	2	2	1	0	6	7%
1 – Highly unlikely	0	0	0	1	0	1	2	2%
Total answers	15	15	15	15	15	15	90	1

Though the general trend was that the high-level roadmap was likely achievable, the workshop discussions and survey did provide input for improvements. The following changes were there for made to better align with the stakeholder opinions:

- Assumptions and limitations were added in section 3.1, where some clarifications were added, such as the scope of proposed policy actions, and the roadmap being our best guess for future developments and constraints that must be overcome.
- The shortsea segment development steps were somewhat changed to include uncrewed operations in territorial waters for shorter distances, at an earlier stage than previously indicated. This is related to feedback on plans for such operations within this timeframe being present with the ZULU MASS. Unmanned shortsea in general (including international waters) was kept at a later stage, as indicated in the draft. Figure 3 updated.
- The use of the word “concept” was reduced. As pointed out by one of the advisory board members, we are mostly not talking about concepts but actual commercial operations.
- The sheltered water shuttles definition was updated to make a better distinction between this definition and shortsea.
- The need for COLREG update was debated. As a response to this, the section 3.1.1 was added to provide our view on AI and ML limitations and how these make an update of COLREG likely to be required.
- The use of the terms remote control and remote control centre was criticised for being used. This because it may lead to the misconception that we mean direct remote control where the operator is constantly adjusting levers and setpoints and could be understood as conventional operations where the bridge is moved to a remote location. We updated the definition somewhat but kept the terms as these are in line with (ISO, 2022).

- A clarification of the CA standard RCC technological development step was included, based on discussions in the meeting with the strategic advisory board.

14.2. CONSTRAINING FACTORS SURVEY RESULTS

The survey asked for how well the main constraining factors are covered in the high-level roadmap (while pointing out that more details are given in the constraining factors section). None of the respondents disagreed, while half of the responses (seven) corresponded to neither agree or disagree, six agree and two fully agree. Resulting in an average of 3.67. Curiously, the responses for “solving the constraining factors for the given time-period enables taking the next realisation step” were lower than 3.67 for all periods (from 3.27 to 3.53)[14]. This is likely caused by few responses to the survey, resulting on high impact on the average per answer.

There was also a free-text input for commenting on these questions where it is indicated that it is difficult to assess the questions (which we agree to, prediction is difficult). It was also stated that international incentives are required and should be highlighted more, though this was already discussed in quite some detail under section 3.4. One respondent points out that the global context is missing and that it is hard to imagine that a common funding action is taken globally. Without such global actions, the respondent finds investments on the indicated scale not realistic. Though we agree to this view, the focus of our work in terms of funding is recommendations towards the European Commission. We still recognise that this constraining factor is not addressed in sufficient detail, which is also why we propose in section 3.4 that further studies into policy strategies are launched.

In response to the survey and discussions, we made some changes:

- Figure 3 updated (added constraining factor for SSS in period up to 2030, updated some of the ship concept descriptions)
- Figure 4 updated (specifically regulations and policy actions)
- In section 3.1 we included a discussion on how we view the European role in accelerating uptake through policies.

[14] The scale is 1 to 5, where 1 means “I completely disagree”, 3 means “I neither agree or disagree”, and 5 means “I fully agree”.

14.3. POLICY ACTIONS SURVEY RESULTS

The survey asked for the respondents to rate[15] how well suited the proposed policy actions were to stimulate overcoming the identified constraints. It should be noted that the draft included policy actions up until 2040, while the final version includes policy actions up until 2045. The results average from 3.4 to 3.6, which indicates that the participants mostly find our proposals suitable. Through workshop discussions and the free-text part of the survey, we also find that the participants believe that more or other actions might be needed in addition to what we suggest. This is also in line with our own opinion; we propose some policy actions but perhaps more importantly that a strategy is formed and that studies on this topic should be launched.

In the free-text input for this part of the survey it was pointed out that digitalisation and the integration of the entire logistic chain is important, and that policy actions to increment TRL in this respect are needed. Furthermore, it was stated that IWW needs to adopt similar thinking as IMO. No other concrete suggestions for changes or amendments to the proposed policy actions were given.

In response to the survey and discussions, we made the following changes:

- Figure 4 updated (specifically regulations and policy actions)
  Digitalisation and integration of the entire logistic chain is not evaluated in detail in this report. This limitation is now highlighted in section 3.1.
  It is highlighted in section 3.1 that the roadmap is our best guess based on the information that is available to us, and that we do expect cases deviating from our prediction to appear tin the future. Furthermore, that the roadmap does provide proposals for how uptake of autonomy can be accelerated.
  We added our view that though EU funding actions cannot cover global investment needs, they can contribute to accelerate developments and thus uptake.

[15] On a scale of 1 to 5 where 1 means "I completely disagree", 3 means "I neither agree or disagree", and 5 means "I fully agree".

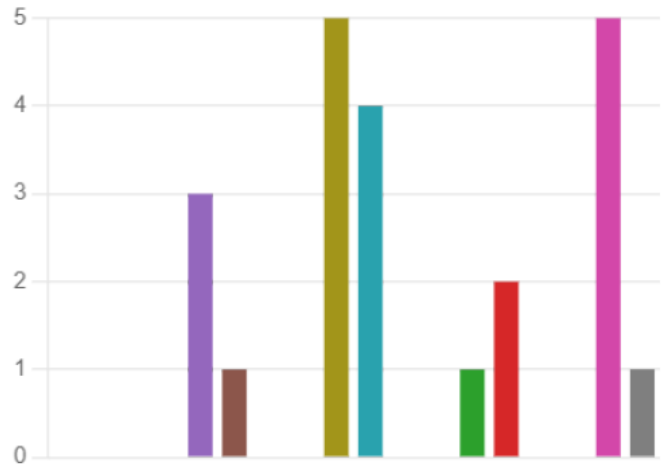
14.4. SURVEY RESULTS

Roadmap to intercontinental autonomous maritime logistics

15	20:07	Closed
Responses	Average time to complete	Status

1. What stakeholder group describes you best?

Cargo owner	0
General public	0
Infrastructure service provider	0
Insurance	0
National authorities	3
Policy maker	1
Port	0
Port operator	0
Regulator	5
Researcher/Academia	4
Sector association, interest grou...	0
Ship owner	0
Ship operator (including RCC op...	1
Ship owner and operator	2
Shipper	0
Standardisation organisation	0
Technology provider	5
Other	1



2. If you belong to more than one stakeholder category or your category was missing, please enter manually here:

3 Responses

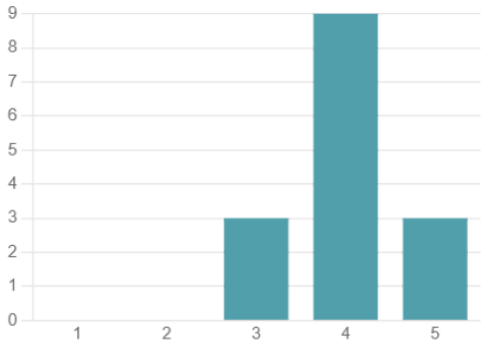
ID ↑	Name	Responses	Language
1	anonymous	General public	Norsk bokmål (Norge)
2	anonymous	UK MASRWG, UNECE and various commercial organisations	English (United Kingdom)
3	anonymous	Classification Society	Norsk bokmål (Norge)

3. What sector do you work whitin?

Shortsea	7
Inland waterways	3
Deep-sea	3
No specific sector	8

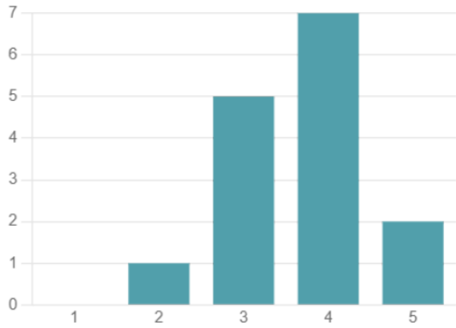
4. On a scale of 1 to 5 where 1 means "I find it highly unlikely", 3 means "I find it possible (50/50 chance)", and 5 means "I find it highly likely", **rate how likely you think it is that it is possible to achieve the targets for 2025.**

4.00
Average Rating



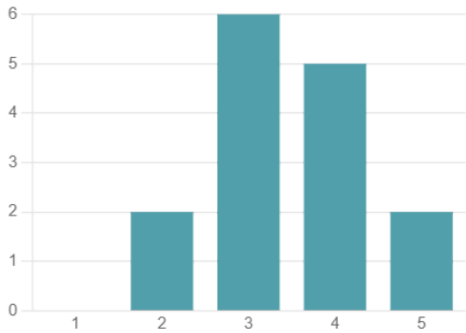
5. On a scale of 1 to 5 where 1 means "I find it highly unlikely", 3 means "I find it possible (50/50 chance)", and 5 means "I find it highly likely", **rate how likely you think it is that it is possible to achieve the targets for 2030.**

3.67
Average Rating



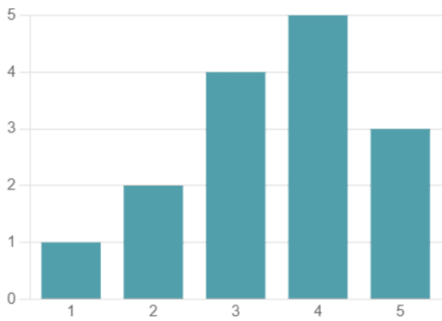
6. On a scale of 1 to 5 where 1 means "I find it highly unlikely", 3 means "I find it possible (50/50 chance)", and 5 means "I find it highly likely", **rate how likely you think it is that it is possible to achieve the targets for 2035.**

3.47
Average Rating

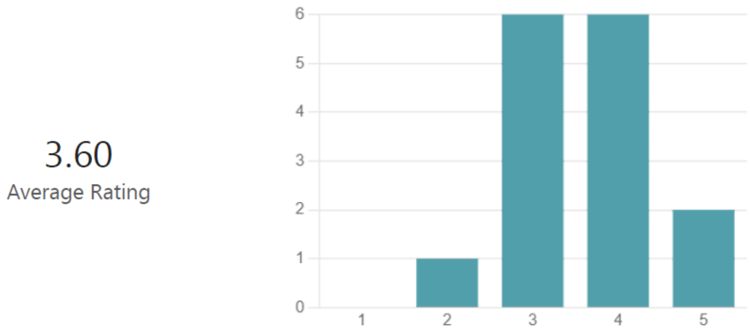


7. On a scale of 1 to 5 where 1 means "I find it highly unlikely", 3 means "I find it possible (50/50 chance)", and 5 means "I find it highly likely", **rate how likely you think it is that it is possible to achieve the targets for 2040.**

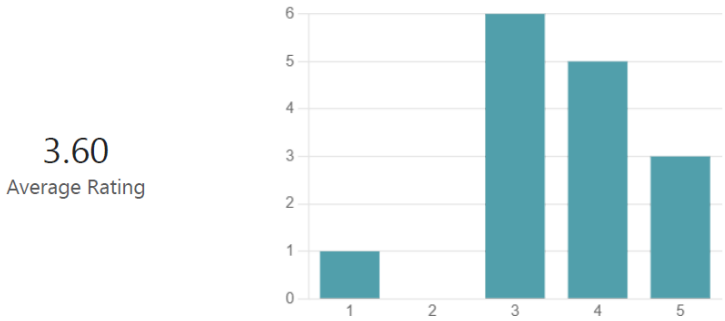
3.47
Average Rating



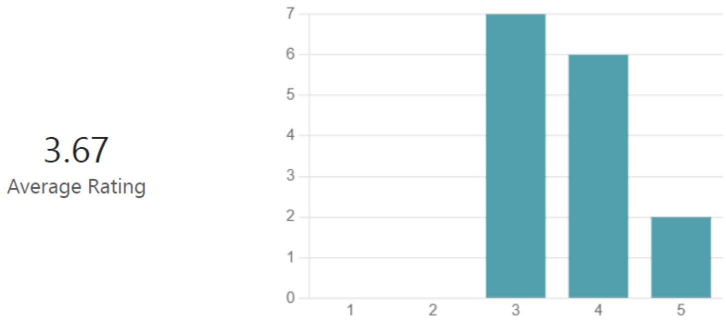
8. On a scale of 1 to 5 where 1 means "I find it highly unlikely", 3 means "I find it possible (50/50 chance)", and 5 means "I find it highly likely", **rate how likely you think it is that it is possible to achieve the targets for 2045.**



9. On a scale of 1 to 5 where 1 means "I find it highly unlikely", 3 means "I find it possible (50/50 chance)", and 5 means "I find it highly likely", **rate how likely you think it is that it is possible to achieve the targets for 2050.**



10. On a scale of 1 to 5, where 1 means "I completely disagree", and 5 means "I completely agree", rate to what extent you agree to the main constraining factors given in the high-level roadmap (in green color). Note that the more detailed constraints will be discussed shortly and that those listed here are the ones considered most important for each period.



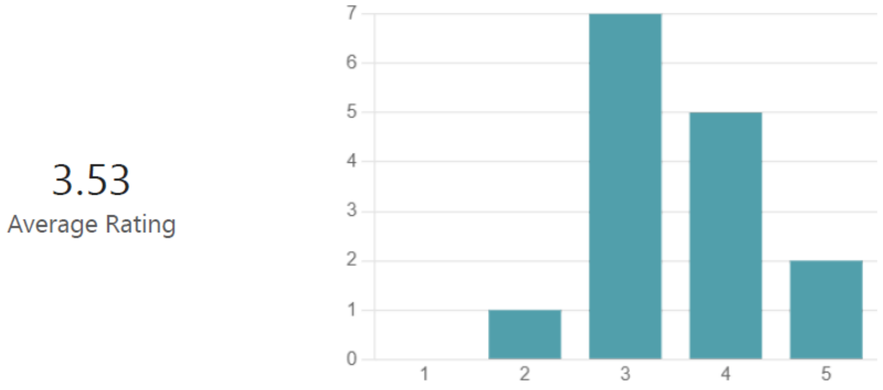
11. If you have comments to your rating of the main constraining factors, please provide them here:

7
Responses

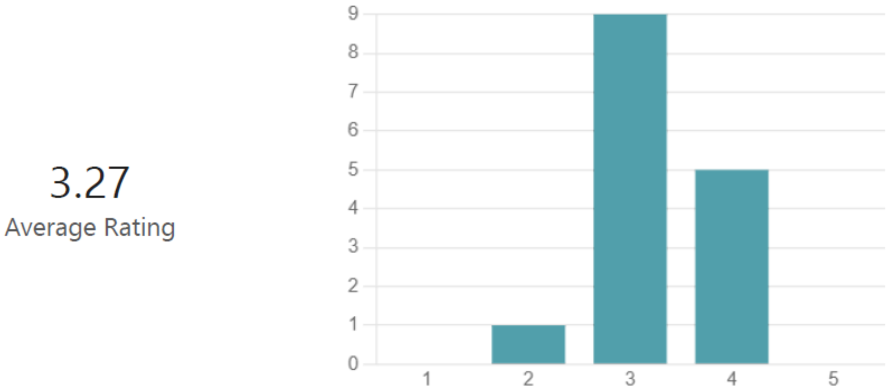
Latest Responses

Responses
Public trust is vital and not easily achievable. But, maybe not as the most important.
Only speaking about IWW, EU legislation is indeed the main constraining factor but River Commissions (esp. CCNR) will also play a critical role through their own binding regulations (for example in Switzerland) and in setting IWT standards (ES-TRIN, ES-QIN, ES-RIS...) that will greatly impact what path automation will take in inland navigation.
There is going to be a lot of difference between various types (sizes) of ships and the environment that is sails in. For small USV's development of legislation will go a lot faster then for big ships.
This is too complex for 1 single answer
I believe that the issue of business funding of new ship technologies and public funding of the infrastructures needed to deploy these technologies on a global scale (not just an EU scale) are not adequately considered and may create a very large drag on what can actually be deployed in any of the
Main constraining factors are the economy, business models and technology (use of general AI)
To describe AUTOSHIP vessels as 'remote control' is not correct.

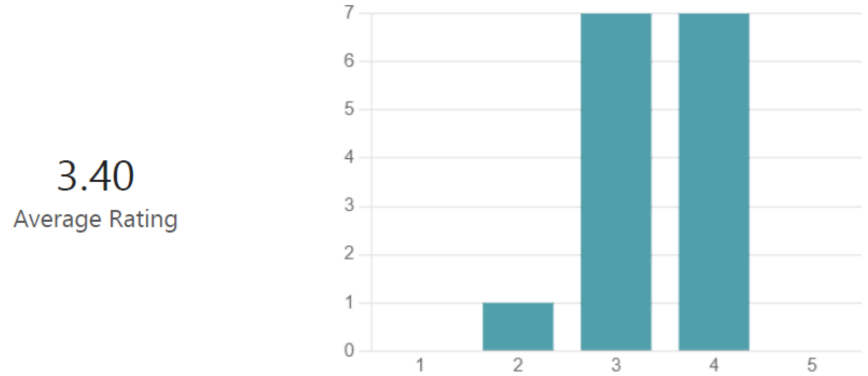
12. Solving the constraining factors for the given time-period enables taking the next realisation step of the high-level realisation roadmap. On a scale of 1 to 5 where 1 means "I completely disagree", 3 means "I neither agree or disagree", and 5 means "I fully agree", rate whether you think that the important constraining factors for the period up until 2025 are included.



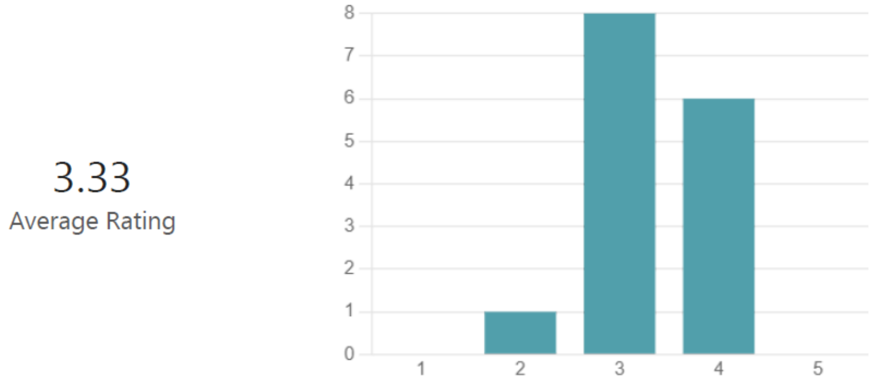
13. Solving the constraining factors for the given time-period enables taking the next realisation step of the high-level realisation roadmap. On a scale of 1 to 5 where 1 means "I completely disagree", 3 means "I neither agree or disagree", and 5 means "I fully agree", rate whether you think that the important constraining factors for the period up until 2030 are included.



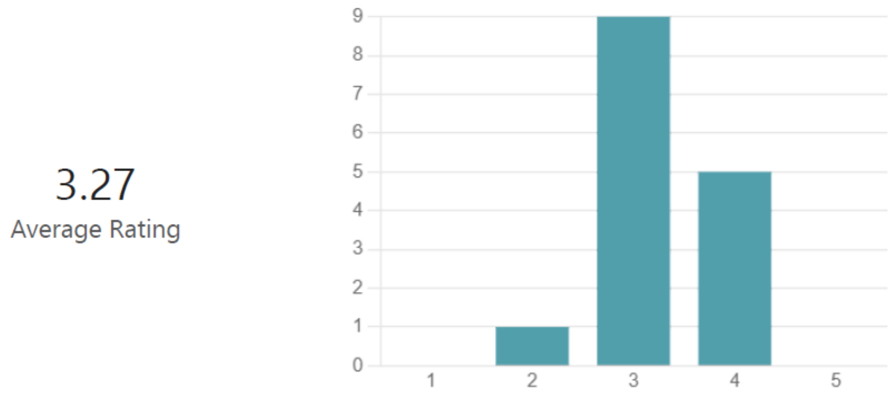
14. Solving the constraining factors for the given time-period enables taking the next realisation step of the high-level realisation roadmap. On a scale of 1 to 5 where 1 means "I completely disagree", 3 means "I neither agree or disagree", and 5 means "I fully agree", rate whether you think that the important constraining factors for the period up until 2035 are included.



15. Solving the constraining factors for the given time-period enables taking the next realisation step of the high-level realisation roadmap. On a scale of 1 to 5 where 1 means "I completely disagree", 3 means "I neither agree or disagree", and 5 means "I fully agree", rate whether you think that the important constraining factors for the period up until 2040 are included.



16. Solving the constraining factors for the given time-period enables taking the next realisation step of the high-level realisation roadmap. On a scale of 1 to 5 where 1 means “I completely disagree”, 3 means “I neither agree or disagree”, and 5 means “I fully agree”, rate whether you think that the important constraining factors for the period up until 2045 are included.



17. Suggestions for missing important constraining factors for a given period?

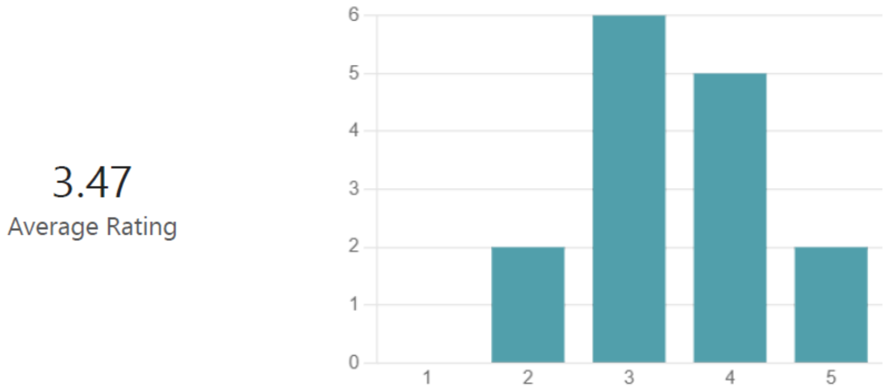
15
Responses

Latest Responses
"-"
"-"
"*No*"

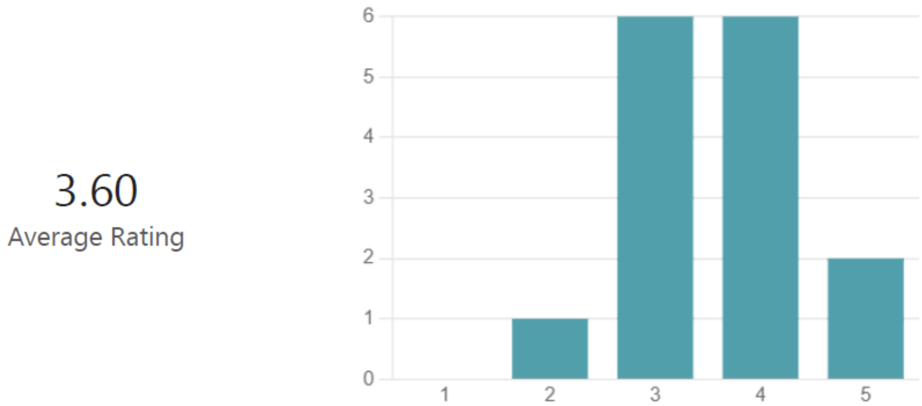
Responses
(Inter)national incentives will be required and should be highlighted more in order to to drive this change, ref your ref to electric cars. in Norway.
Difficult to assess which factors will be most critical at which time. Societal factors might be more problematic post 2035 when automation is rolled out large-scale and issues/accidents/successes become more apparent, thereby generating push-back either for security purposes or because crews go out of business by being outcompeted by machines. Furthermore, I think a critical bottleneck will be the development of advanced AI and computer systems/algorithms, which require crazy ammounts of energy/bandwitdth to work properly, so remote control might be very tricky in the open ocean.
This highly depending on the type op shipping we are talking about.
To be discussed separately
No

Here again I believe that the international context is missing. While the EU may do something to support the development of autonomous ships and appropriate infrastructures, it is hard to imagine that this will be the common action taken globally. With out global compliance I would think that international shipping companies will not invest in autonomy on the scale envisioned.
adequacy of the technology - the more you move from AO to FA the more you need to demonstrate that general AI can do the job.
No
no
no
None.
There are no missing constraining factors from my point of view
No
-
-

18. The suggested policy actions are intended to stimulate activities towards overcoming constraining factors that we believe would not be overcome within the time-period otherwise. On a scale of 1 to 5 where 1 means “I completely disagree”, 3 means “I neither agree or disagree”, and 5 means “I fully agree”, rate whether you agree that the policy actions suggested to be launched in the priod up until 2025 are suitable

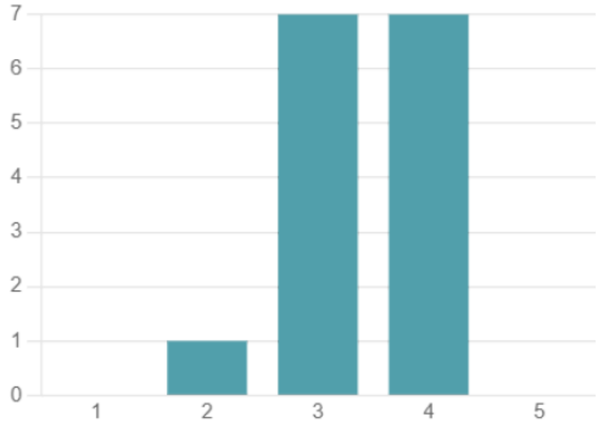


19. The suggested policy actions are intended to stimulate activities towards overcoming constraining factors that we believe would not be overcome within the time-period otherwise. On a scale of 1 to 5 where 1 means “I completely disagree”, 3 means “I neither agree or disagree”, and 5 means “I fully agree”, rate whether you agree that the policy actions suggested to be launched in the priod up until 2030 are suitable



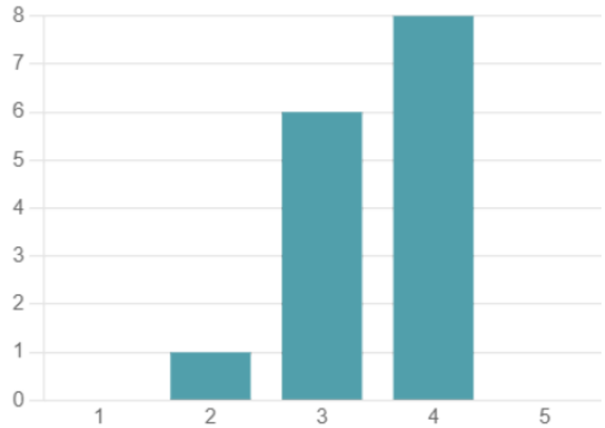
20. The suggested policy actions are intended to stimulate activities towards overcoming constraining factors that we believe would not be overcome within the time-period otherwise. On a scale of 1 to 5 where 1 means “I completely disagree”, 3 means “I neither agree or disagree”, and 5 means “I fully agree”, rate whether you agree that the policy actions suggested to be launched in the priod up until 2035 are suitable

3.40
Average Rating



21. The suggested policy actions are intended to stimulate activities towards overcoming constraining factors that we believe would not be overcome within the time-period otherwise. On a scale of 1 to 5 where 1 means “I completely disagree”, 3 means “I neither agree or disagree”, and 5 means “I fully agree”, rate whether you agree that the policy actions suggested to be launched in the priod up until 2040 are suitable

3.47
Average Rating



22. Any suggestion for additional policy action or input to action that should be modified or that you disagree to?

15
Responses

Latest Responses
"-"
"-"
"IWW needs to have similar thinking than IMO has for the D...

Responses
Digitalization and Integration of the entire logistics chain will be very important. Public support practical, TRL-incremental use-cases in this respect!
Again, I don't think it's possible/realistic to predict past 2030/2035 with any degree of accuracy.
I cannot answer these questions, since the type of shipping (inland, sea) is completely different
I think the timelines are far too extended in general
No
No.
none
No
no
No
None.
No comments.
IWW needs to have similar thinking than IMO has for the DSS
-
-

23. Any final comments?

Latest Responses

15
Responses

"-"

"-"

"The prediction is difficult, especially of the future. the 2025 i...

Responses

Input based upon "chapter 3" of the report only.

Good job overall, but refine the assumptions behind some claims and add more nuance/conditionality/uncertainty about predictions in the far future (2040/2050).

no

The roadmap gives a rather misleading impression about where we are and what happens in the next 30 years. We need to avoid setting false targets based on debatable assumptions.

No

Keep in mind that it is not technology that will limit or slow uptake, but the ability of companies and nations to finance the changes needed. Remember that it took over 30+ years for container shipping to establish itself as the primary mode of freight movement (for those items that are not bulk) for global trade. This was partially due to labor fighting the change, but also due to the capital investments required from shipping companies and port operators. These factors have not gone away and will be major drags on uptake of autonomy on a global scale.

It would be interesting compare the initial forecast of the car industry with the actual delivery. We might learn something.

No

I don't understand why you use RCC. In the AUTOSHIP project, we use Remote Operations Centre, not Remote Control Centre. The term 'remote control' should not be used in the context of autonomous ships, except when talking about the rare exception when an operator actually takes remote control of a vessel.

Thank you - for the interesting auto ship summary

None.

No comments.

The prediction is difficult, especially of the future. the 2025 is easy to understand and somewhat 2030. but the actions that are leading to 2030 should already be there.

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