A technology development roadmap for autonomous shipping

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Main editor: Dr. Ir. R.G. Hekkenberg – TU Delft

Editors: Ir. E.M. Krikke – Netherlands Maritime Technology
Ir. J.H.de Jong - MARIN
Dr. Ir. H. Bastiaansen - TNO

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1. Summary

This report is the final deliverable of the Dutch Joint Industry Project Autonomous Shipping which ran from 2017 to 2019. It provides a development roadmap for autonomous shipping, based on the findings in the project. The roadmap is subdivided in 4 main topics, related to navigation, crew tasks & ship design, collection, processing & communication of data, and equivalent safety. Each of these topics has important technological milestones that need to be achieved before autonomous shipping can be implemented on a large scale. For each milestone and for various use cases (ocean crossing shipping, short sea shipping, inland shipping and wind park crew transport) it has been determined what the current (2019) TRL of the milestone is and at which ALFUS autonomy level it starts adding value. The report also provides descriptions of the added value, the required development steps and the important boundary conditions and limitations for the application of each milestone.

For an overview of all documents that were developed within this JIP and that form the basis for this roadmap, the reader is referred to chapter 2 'Introduction'.

The main conclusions from this roadmap are organized along the four main topics as defined above: navigation, crew tasks & ship design, the collection, processing & communication of data, and equivalent safety.

Navigation

The description of developments uses the well-known plan-decide-act loop and defines these developments within the typical navigation planning horizons (voyage (6h-updates), traffic avoidance[1], collision avoidance & close in operations). The prerequisite for development of autonomous navigation systems is the availability of reliable and accurate data from sensors.

Route planning tools as well as ship and cargo safety monitoring tools are vital in the human directed long and medium term planning of voyages. To make these tools available requires an engineering effort.

To determine the levels of risks in various traffic conditions, risk level modelling and tooling is needed. These models are not available yet. This requires physical modelling of the manoeuvring in the full speed range. Both in open waters and in confined areas, including ship - tug – infrastructure dynamics. These models also include ship-ship communication aspects like share and confirm intention actions. Also modelling of the Rules of the Road to avoid collisions and demonstrate good seamanship is needed to determine risk levels. Artificial Intelligence based upon extended ship-to ship & shore encounters & communication and environment modelling can further enhance the long (weather) and medium term planning and decision making.

Improvements are needed on Man Machine interface issues concerning alerting functions and the presentation of decision alternatives.

[1] Traffic avoidance anticipates on future encounter situations by either slightly changing speed or course to avoid COLREGS applicable situations.

These developments are providing a basis for an efficient safety assessment framework, which is needed to continuously verify and validate the new systems in the evolving contexts. The latter includes the continuous generation of new benchmark scenarios and related criteria. The former the inclusion of risk mitigation measures and contingency strategies.

Ocean crossing large cargo shipping may soon benefit up to human directed an human aided applications. For short sea shipping intermittent unmanned bridge operations during the longer hauls with limited collision avoidance type of interactions may be introduced up to human aided applications.

Crew tasks & ship design

The solutions to replace the majority of crew tasks are typically at a high TRL level, with the exception of advanced machinery concepts which include batteries and fuel cells. The integration of these technologies still need a significant development to achieve viable solutions. The time to bring the high-TRL solutions to a market-ready product or implemented service mainly depends on the engineering effort that is invested. An important finding related to the replacement of crew tasks is that many solutions are organizational in nature rather than technological. Tasks like administration, maintenance, having responsibility are typically extremely expensive and/or difficult to fully automate. Transferring these tasks to shore based human solutions seem to be much more promising.

Notwithstanding this, further enhancement and integration of existing technology is a prerequisite to enable these shore-based human solutions. Especially related to the main machinery, improvements in condition monitoring, reliability and/or robustness are needed, even though the technology required to achieve this is typically already at a high TRL. A final important conclusion is that standalone solutions like automated navigation and automated mooring do not lead to large crew size reductions. Only a combination of solutions AND a reconsideration of the roles, tasks and responsibility of crew members will make large crew size reductions possible.

Collection, processing and communication of data

A main driver for collection and processing of data for autonomous and unmanned shipping is in supporting the automating of the decision-making processes (e.g. on navigation), which are currently being made by the human crew on board. For data collection for autonomous and unmanned shipping, the sensors onboard will need to be complemented with camera's, LIDARS and radar systems for specific observation tasks directly around the ship and long-range details (that are currently observed by humans). The installation of additional EO/IR camera system and additional radars for measuring distance from bow and stern to the quay will cover the majority of the perception requirements for the decision-making processes on navigation.

Nevertheless, full hundred percent certainty on the autonomous decisions made onboard under all conditions and in all external situations/contexts may appear to be an utopia. As such, risk mitigation becomes a key element for operating autonomous and unmanned ships, with the overall system design being based on the principle of 'design-for-uncertainty', in which the situations are detected and acted upon that are beyond the boundaries of the design limits of the autonomous decision-making functions. The autonomous ship's onboard software modules need to be developed on the requirements for 'health status estimation', 'data reliability and self-awareness' and 'situation complexity estimation'. Mitigation measures and contingency solution must be provided in the form of enabling the transition / switch from an autonomous shipping operational modus to another operational modus such as a remote controlled or a failsafe operational modus.

The autonomous ship's onboard software modules need to be developed with 'health status estimation' and 'situation complexity estimation' functionality for contingency planning. The concept of 'equivalent safety' in assessing the combination of the quality of the ship's systems, the risk mitigation measures and the contingency strategies on their trustworthiness for autonomous shipping needs further development to support regulations and adoption.

Equivalent safety

The ability to assess the equivalent safety of an autonomous or unmanned ship compared to traditional ships is vital for regulatory acceptance by flag states and IMO as well as for introduction of the concept of autonomy in society and the market. The level of safety being equivalent to conventional ships applies even in (navigation) situations of high shipping complexity and/or uncertainty due to environmental or system health conditions. It implies that the risks and risk mitigation for autonomous ships are transferred from crew to sensors, software and communication systems, requiring a (continuous) testing and a certification process based upon evolving and emerging shipping scenarios including 'mixed' traffic scenarios.

In addition to the health status estimation' and 'situation complexity estimation' functionality for contingency planning, methodology and tooling for assessing equivalent safety of autonomous and unmanned ships should be developed, test scenarios suitable for assessing safety of autonomously operated ships should be generated, and safety surveillance and response concepts and systems for the autonomous or unmanned ships operating in combination with its shore control center (SCC) should be developed.

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2. Introduction

This report is the final deliverable of the Dutch Joint Industry Project Autonomous Shipping which was executed from 2017 to 2019. It provides a development roadmap towards autonomous shipping, based on the findings in the project. The roadmap is subdivided in 3 main topics, related to the crew tasks, the collection, processing & communication of data and finally navigation. Each of these topics has important technological milestones that need to be achieved before autonomous shipping can be implemented on a large scale.

2.1 Setup of the analysis

In this roadmap, it has been a deliberate choice not to mention expected realisation dates for these milestones, but rather to define the current (2019) TRL levels of these milestones. This serves as a handhold to estimate the required effort to realise full maturity for these technologies and thus allows estimation of the required effort to realise autonomous shipping in various forms.

The definitions of the used Technology Readiness Levels (TRL) are:

TRL	Definition
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)

It is important to realise that many of the technologies that are required for autonomous shipping do not just add value for fully autonomous ships. Many of them start adding value much earlier for conventional ships on the road to higher autonomy levels by e.g. increasing safety, reducing workload or improving reliability. For each of the analysed technologies, it is therefore determined when they start adding value. This is done using the ALFUS autonomy scale as presented below:

ALFUS autonomy scale

Level 0 (Manual control): *The operational case where the system is manned and has neither self-determination nor independence. All sensing, perceiving, analysing, planning, and decision-making are done by the human; the human directs all unmanned system actions from the human's frame of reference;*

Level 1 (Remote Control): *The operational case with an unmanned system afforded neither self-determination nor independence. All sensing, perceiving, analysing, planning, and decision-making are done by the human; the human directs all unmanned system actions from the human's frame of reference; the case of maximum human influence over unmanned performance.*

Level 2 (Tele-operation): *The operational case with an unmanned system performing out of the direct observation of the human controller, requiring the unmanned system to sense its environment and report its state to the human; all analyzing, planning, and decision-making are done by the human; most perceiving is done by the human; the human directs all unmanned system actions from the machine's frame of reference.*

Level 3 (Human Directed): *The operational case with an unmanned system performing out of the direct observation of the human controller, requiring the unmanned system to sense its environment and report its state to the human; most analyzing, planning, and decision-making are done by the human; perceiving and acting are shared between the human and the unmanned system.*

Level 4 (Human Aided): *The operational case with an unmanned system performing out of the direct observation of the human controller, requiring the unmanned system to sense its environment and report its state to the human; analyzing, planning, and decision-making are shared between the human and the machine; most perceiving and acting are done by the unmanned system.*

Level 5 (Autonomous): *The operational case with an unmanned system afforded the maximum degree of independence and self-determination within the context of the system's capabilities and limitations; the case of minimum human influence over unmanned performance; an unmanned system performing out of the direct observation of the human controller, requiring the unmanned system to sense its environment and report its state to the human; all perceiving and acting are conducted by the machine; most planning and decision-making are conducted by the unmanned system; negotiation and cooperation must be performed by the human.*

In the elaboration of the milestones in the remainder of this report, the applicability of these ALFUS levels will differ per domain / aspect. For some of the domains / aspects it is most suitable to apply them system level (e.g. for the machinery), for others it is most suitable to apply them at the level of the overall ship (e.g. for sensors). This difference is made as the various domains / aspects are in a different status of automation: the (maintenance) of machinery currently involves manual tasks, whereas sensors (and other IT-systems) are already automated and operating autonomously per definition. For the latter case however, it can be assessed what their TRL level is in contributing to the level of autonomy for the overall ship in the various use cases. In the tables visualising the status for each of the domains/aspects, the header includes whether it applies to the system or the ship level.

It should also be realised that there is no single solution for global autonomous shipping, but that ship/platform type, operational profile, area of operation, governing regulations, properties of waterways and traffic flows all influence the required mix of technical and organizational solutions. In this roadmap the required developments are, therefore, described for four use cases:

1: Ocean crossing large cargo shipping; large ships with straightforward operational profiles that operate uninterrupted on long sailing legs, mainly on open seas and oceans with limited traffic density (TSS navigation excluded). Ships may operate far beyond the range of shore-based broadband communication networks.

2: Short sea shipping; smaller ships that mainly operate on busy traffic lanes and have frequent port calls. They thus encounter complex traffic situations far more often than in use case 1. Their sailing legs are typically relatively short and close to shore, where communication network coverage is expected to be good/acceptable.

3: Inland shipping (incl. operation in estuaries & ports); Small, relatively elementary ships that operate in a complex nautical environment with currents, changing water depths, busy traffic and narrow traffic lanes. They always operate close to places of refuge and typically have short sailing legs of no more than appx 200-300 kms.

4: Wind park crew transport; Small, relatively fast ships that mainly operate outside shipping lanes on frequent short sailing legs.

In the following chapters, the various milestones and their current TRL level are assessed for various use cases. it is also determined what the lowest autonomy level that the associated process(ses) or system(s) need to have to add value. Note that a single ALFUS level cannot be defined for a ship, since it is a complex system of systems that can incorporate a wide range of ALFUS levels. E.g. navigation can be at a very high ALFUS level, where the engine room still operates at a very low level.

Results per topic are summarized in tables as shown below. Each milestone is placed in a colored row, where orange means that TRL is currently low (1-3), yellow means a medium TRL (4-6) and green is a high TRL (7-9).

As an example, automated mooring, milestone F of section 'miscellaneous crew tasks' can currently be bought off the shelf, placing it at TRL level 9, i.e. in the green rows of the table. Since such a system needs to take over at least some analysing, planning, and decision-making from the human, it operates at least at ALFUS level 3 (see box on ALFUS levels). The concept is applicable to all use cases, so it is placed on all four green rows.

topic							
		ALFUS autonomy level applied to the system / ship level					
		0	1	2	3	4	5
Use case	1						
					F	**F**	**F**
	2						
					F	**F**	**F**
	3						
					F	**F**	**F**
	4						
					F	**F**	**F**

2.2 Report structure

The milestones that are discussed in this report are grouped along the research lines of the joint industry project.

The milestones in **chapter 3** cover the milestones on the road towards autonomous navigation. They are subdivided into 'planning', decision 'making' and acting. This covers **work package 2** of the JIP.

The milestones in **chapter 4** are related to the tasks of the crew and the aspects of the ship's design that are typically covered by a naval architect or marine engineer. The milestones are subdivided into 'main machinery support' and 'miscellaneous crew tasks'. This covers **work packages 1, 3 and 5** of the JIP.

In **chapter 5**, milestones arising from **work package 4, '**Collection, processing and communication of data' are discussed, subdivided into 'situational awareness, 'operational alignment' and 'communications'.

2.3 Underlying documentation

This report is built on the research done in this JIP. This research is, however, more extensive than what is presented here. Therefore, a complete overview of all delivered documents that underlying this report are listed below, in the order in which the topics are treated in this document.

WP1, 3 and 5 – Crew tasks and ship design

- Report 'Literature review'
- Report 'Results ship system workshop'
- Report 'Functional Breakdown and autonomy levels'
- Report 'Design for Unmanned Operations', TNO 2019 R12184
- Journal article: "The Effect of Autonomous Systems on the Crew Size of Ships – a Case Study", submitted to Maritime Policy & Management, under review.
- Conference paper: "Towards autonomous shipping: operational challenges of unmanned short sea cargo vessels", submitted for International Marine Design Conference
- Conference paper: "Towards Unmanned Cargo-Ships: The Effects of Automating Navigational Tasks on Crewing Levels" presented at COMPIT 2019
- Master thesis Joost Colon: "Identifying and eliminating weak points inhip's machinery plants, A step towards continuously unmanned engine rooms"
- Master thesis Elmer Brocken: "Improving The Reliability Of Ship Machinery, A Step Towards Unmanned Shipping"

WP2 – Navigation / Traffic management

- Preliminary report scenario generation, 30531.500, 2017
- Definition of Nautical scenarios, 30531-1-MSCN, 2018
- AIS data analysis of maintained passing distances during ship encounters, 30531-4-MSCN, 2020.

WP4 – Collection, processing and communication of data

- Paper 'A Business Process Framework and Operations Map for Maritime Autonomous and Unmanned Shipping: MAUSOM, TNO

- TNO ‘Final report WP 4’, 2018 R10444

WP6 & WP7 – Preparation of demo’s & Execution of demo’s

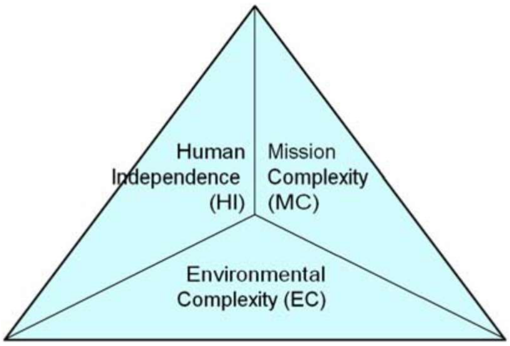
- Report ‘Trials plan’, 30531-2-MSCN, 2019
- Report ‘Sea trials’, 30531-3-MSCN, 2019
- Demo en veiligheidsplan voor de demonstratie op zee van autonoom varen in het Joint Industry Project Autonomous Shipping, NMT v0.4, 190222
- Report ‘Risk mapping and contracts for the autonomous sea trials SEAZIP’, AON
- Report ‘ 22914 - JIP autonomous shipping - technical evaluation, Damen Shipyards 3858576.A
- Report ‘ Joint Industry Project – Autonomous Sailing – Special trials’ , Robosys 190505

WP8 – Roadmap

- Conference paper: “When will autonomous ships arrive? A technological forecasting perspective”, presented at the 14th international naval engineering conference, 2018
- Presentation MIWB “Raak Pro Maritieme Veiligheid/ JIP Autonomous Shipping – Legal Aspects”, 2019

3. Navigation

Navigation on (autonomous) ships is key to the safety and efficiency of a ship's operation and requires up till now a permanent and in some locations intense human involvement both on board as well as ashore. Proving an equivalent safety level for every level of autonomy and ever-changing context is essential.
The evolution of autonomy is highly contextually defined and requires a definition of that context and related scenarios addressing the complexity of the mission and the operating environment [1,2,3]. The selected use cases largely define the complexity levels of both mission and environment.
See the three aspects of autonomy in the figure below.



The milestones below use the framework formed by the ALFUS autonomy level definitions and the control loop aspects. The distribution of tasks between man and machine is then made specific for the proposed Use Cases. The Use Cases all assume a manned operation with increasing intervals of unattended watch keeping on the bridge. The ALFUS level is a means to define the frequency and intensity of interaction based upon the appropriate alerting functions as part of the decision-making system.

Within the domain Navigation 3 subtopics have been defined following the control loop aspects: Planning, deciding and acting. Each of these is discussed below.

3.1 Domain/aspect: Planning

Route planning (tracks & speed) has distinguished time horizons each with their appropriate situational awareness and three levels of human interaction. Next to the initial overall commercial, destination route planning ('long'), intermediate updates are prepared at regular intervals to account for time loss/gain or (to be avoided) weather systems ('medium'). The third level addresses the immediate assessment of emerging traffic conditions, port approaches and/or external communications which require an unforeseen manoeuvre ('short').
These planning levels will likely still pertain to the various future levels of autonomy with the possible exception of the medium planning, which could extend into a continuous updating (or as often as new weather info arrives). The higher autonomy levels could further include the avoidance of future traffic scenarios at all by making small but early course/speed alterations to avoid coming in conflict with other traffic.

The second aspect of planning refers to the non-negotiable safety of ship and cargo aspects (The Ship & Cargo Safety Monitoring). Although the weather routing part of the planning ('medium') accounts primarily for the commercially driven alternative route choices, safety considerations will accounted for. In many cases the chosen alternative is just slowing down/speeding up or making small course deviations, if possible or choosing alternative TSS (Traffic Separation Scheme) routes for reasons of safety. The choices between planning options presented take also account of either predicted or experienced limiting vessel motions. The final route choice to be made in the decision phase.

Milestones are:

A) Human directed *long- & medium-term* planning capability in open waters at speed in all weather and *low traffic density*
B) Human aided long- & *medium- & short-term* planning capability in open waters at speed in all weather and *all traffic conditions*
C) Human supervised long-, medium- & short-term planning capability at *all speeds* in all weather and all traffic conditions (*special manoeuvres*)

Planning capability							
		ALFUS autonomy level applied to the system level					
		0	1	2	3	4	5
Use case	1						
						B	C
					A		
	2						
						B	C
					A		
	3						
						B	C
	4						
					A	B	C

Milestone code A: Human directed long- & medium-term planning capability in open waters at speed in all weather and low traffic density.

ALFUS autonomy level: 3
Current TRL: 7/8

Relevance for the path to autonomous shipping:
Autonomous and highly automated ships need voyage planning systems which automatically establish tracks and speed planning and prepare deviations emerging for long and medium ranges (pro-active planning). This voyage planning is based upon an initial voyage instruction (mission), more global environment situational awareness (predictions) and medium-term traffic information (encounter prediction).

Description of added value per use case:
Long- and medium-term planning can be effectively used during the long ocean crossings of use case 1 and for shorter periods in non-route committed short sea operations in low traffic density areas. Although most automated planning contributing to the autonomy level only comes in at level 4, it can contribute from level 3 onwards for the mentioned use cases. Survey vessels / platforms can use it for their operations as soon as in sailing in open waters. All other use cases can use it as route planning system in a unmanned ALFUS level 1 and 2 situation.

Required development steps:
The technology is close to available today (TRL 7-8) but developing a suitable, ship specific route planning system for a given ship will still require an engineering effort. A sufficient level of medium distance vessel track prediction of the own ship and the surrounding traffic is to be developed on

the basis of evolving AIS information and vessels' main particulars and manoeuvring models. The Ship & Cargo Safety Monitoring planning isn't widely adopted in the industry although the TRL level of the underlying technologies is high (TRL 8). Its development needs the identification of the limiting motion criteria (cargo & humans) to base the planning on. Improvements are needed on Man Machine Interfacing concerning alerting functions, the presentation of planning alternatives and planning explaining capabilities. Potentially Artificial Intelligence based upon extended ship-to-ship & shore communication and environment modelling can further enhance the long weather and medium-term traffic planning.

Important limitations & boundary conditions:

The notation 'open waters' in the above milestone definition assumes a vessel sailing at manoeuvring speed. Sensor availability is limited to the normally available systems (ALFUS level 0). Crew is stand-by on board and ready to interfere if alerted. Hence the application of this milestone is limited to those parts of the voyage of the use cases, which allowed crews to rest and/or perform other tasks.

Milestone code B: Human aided long- & medium- & short-term planning capability in open waters at speed in all weather and traffic conditions.

ALFUS autonomy level: 4
Current TRL: 5/6

Relevance for the path to autonomous shipping:

In addition to the level 3 capability of milestone A on route & pro-active rerouting further value is now added to autonomous and highly automated ships through the short term planning of conflict solutions for vessel encounters in more dense traffic and environmentally more extreme conditions. The vessels are sailing at sufficient manoeuvring speed to effectively keep the vessel on track in all weather conditions and keeping ship and cargo safe.

Description of added value per use case:

The short-term planning at speed enables sailing through most dense traffic areas and structured, often route committed, areas. The more complex multiple vessel scenarios require VHF communication with risk of misunderstanding. The proposed planning gives a clear, closed loop communicated and least risk solution. Survey vessels can use it for their transit operations when to cross dense traffic lanes. All other use cases can use it in a manned ALFUS level 4 situation in a shared final decision and eventual negotiation/cooperation with other vessels.

Required development steps:

The full developed technology is not available today due to the ambiguity of the more complex traffic scenarios solutions, which still lean on situational ruling and mariner judgment, supplemented with oral vessel to vessel communication. (TRL 5/6). System development requires:

- the accurate modelling of vessels' manoeuvring behaviour in all environmental conditions,
- the accumulated modelling of the Rules of the Road to avoid collisions and demonstrate good seamanship,
- the modelling of the risk level of the short-term planning contributing to the equivalent safety aspects (complexity and uncertainty) and contingency strategies,
- the capability to share & confirm own & target vessels' intentions,
- the improvement of the man-machine interfacing concerning presentation of the planning alternatives and the planning explaining capabilities,
- the introduction of Artificial Intelligence based upon extended ship-to ship & shore communication, environment and vessel behaviour modelling can further enhance the short term

planning,
- the development of a Safety Assessment framework for a continuous verification & validation,
- the development of a data-driven, stochastic prediction framework for safety assessment i.e. extensive modelling of all involved components, safety assessment and scenario mining using AIS data.

Important limitations & boundary conditions:
An important boundary condition is the high level of Situational Awareness required. It needs an extensive sensor modelling on visual cues related to the proxy environment and objects, and an AI based recognition of these objects. The planning systems needs a human interface which explains the proposed planning solution.

Milestone code C; Human supervised long-, medium- & short-term planning capability at all speeds in all weather & traffic conditions.

ALFUS autonomy level: 5
Current TRL: 4/5

Relevance for the path to autonomous shipping:
In addition to the level 4 capability of milestone B on the short term planning of conflict solutions for vessel encounters level 5 adds capability for the slow speed operations. This planning capability extends the autonomous operations into restricted waters, ports and rivers and enables low speed open water operations (anchoring, people or cargo transfer at sea, extreme weather handling) and extends the level of autonomy. At this level available information is added to the short-term planning capability on the track intentions of some of the encountered vessels.

Description of added value per use case:
The short-term planning at low speeds enables sailing through dense traffic areas in very restricted areas and during ship-to-ship (tugs) or ship-to-object operations. It enhances the safety of operations due to a well explained and shared planning proposal. All other non-described use cases can use it in a manned level 4 situation.

Required development steps:
The technology is not available today (TRL 4/5). System development requires
- the accurate modelling of vessels' slow speed manoeuvring in deep and restricted water behaviour in all environmental conditions,
- the accumulated modelling of good Seamanship in ports and during special operations (pilot on board, mooring, crew transfer)
- to model the risk level of the short-term planning action at low speeds in close encounters contributing to the mentioned equivalent safety aspects (complexity and uncertainty) and contingency strategies.
- the capability to share & confirm own & target vessels' intentions (communication & VTM interaction).
- the improvement of Human factors (in between others MMI) concerning presentation the planning alternatives and planning explaining capabilities.
- the introduction of Artificial Intelligence based upon extended ship-to ship & shore communication, environment and vessel behaviour modelling can further enhance the short term (collision avoidance) planning.
- the development of a Safety Assessment framework for a continuous verification & validation (equivalent safety).

- the development of a data-driven, stochastic prediction framework for safety assessment is needed (extensive modelling of all involved components, safety assessment and scenario mining using AIS data.)

Important limitations & boundary conditions:

An important boundary condition is the high level of self and situational awareness required. It needs an extensive sensor modelling on visual cues related to the proxy environment and objects, and an AI based recognition of these objects. The use of other vessels' track intentions introduces liability issues concerning the reliability and availability of this information. Ship design adjustments have to be realised, facilitating low speed manoeuvring and well-defined procedures for tug assistance interaction reflecting the individual low speed ship manoeuvring properties and the actual local wind and current conditions acting on the ship.

The definition of a simulation-based certification approach including an AI based simulation scenario generator is needed to enable the introduction of this level of short-term planning.

3.2 Domain/aspect: Decision making

The distinction between planning and decision making on each of the time horizons requires a distinctive principle. What defines planning and what decision making. A practical split allocates all non-negotiable tracking boundary conditions to the planning module levels. These modules present the decision (support) system with viable options at each planning time horizon level given the vessel, cargo, mission, environment and traffic context.

At each planning level the decision system is then allocated with the task to assess the available options and make the best and/or good enough choice. The assessment first prioritizes the planning level to be assessed and within these levels the aspects to be weighed like schedule keeping, fuel consumption, cargo & vessel safety next to traffic safety. The weighing could be different for the various planning levels. The decision system then presents and explains the logic of the proposed short-, medium- and long- term planning choices. The weighed balancing of the various alternatives involves moral/legal issues as safety will have to be balanced by commercial considerations.

D) Human *directed (almost) full* open water *navigational decision support* at speed in all weather & *low traffic density* encounters

E) Human *aided full* open water *navigational decision support* at speed in all weather & *all traffic conditions*

F) Human *supervised decision support* at all speeds in all weather & traffic conditions.

Decision making capability							
		ALFUS autonomy level applied to the system level					
		0	1	2	3	4	5
Use case	1						
						E	**E**
					D		
	2						
						E	**F**
					D		
	3						
							F
	4						
							E
					D	**D**	

Milestone code D: Human directed full open water navigational decision support at speed in all weather & low traffic density encounters.

ALFUS autonomy level: 3
Current TRL: 7/8

Relevance for the path to autonomous shipping:

Autonomous and highly automated ships need decision (support) systems which automatically present, explain and choose the proposed planned tracks and speed (long term) and deviations thereof (medium term) given potentially emerging new situations (pro-active planning related). The decision making is based upon the already accepted long & medium term planning and serves the open water temporarily unmanned bridge operation in low density traffic areas. The system raises safety levels as it timely alerts and explains proposed decisions by indicating the level of risk involved for cargo, vessel and traffic encounters. It timely alerts if pre-set schedules are not kept or fuel consumption is over budget.

Description of added value per use case:

Long and medium term decision making can be effectively used during ocean crossings and in non-route committed short sea operations in low traffic density areas. It enables on board crews to focus their attention to other tasks. Survey vessels can use it for their transit operations as soon as in sailing in open waters. Crews can divert there attention to other survey related preparatory tasks.

The systems abate fatigue related lapses and mistakes, potentially leading to incidents, it further optimizes the route planning execution both on schedule keeping and fuel economy aspects.

Required development steps:

The technology is not available today not even for the two-ship COLREG's based encounters (TRL 6-8).

- In an all intentionally non-encounter operation, where a system avoids other traffic through through early encounter recognition using small adjustment of the route planning, the ALFUS level 3 fit solutions exist on TRL 7/8. In such a system there is still a role for the human operator if the traffic situation becomes too complex,
- further development is needed of a suitable decision (support) system handling non-complex two ship open water encounters for a given ship and requires an engineering, verification & validation effort. A traffic risk indicator (encounter safety assessment) tool is part of these developments next to a cargo and vessel risk indicator,
- the improvement of Human factors (between others MMI) concerning alerting functions, the presentation of decision alternatives) and explaining capabilities for these non-complex, timely route proposals,
- Artificial Intelligence based upon extended ship-to ship & shore encounters & communication and environment modelling can further enhance the long (weather) and medium term decision making.
- the development is needed of a certification assessment framework for continuous verification & validation of decision tools (equivalent safety),
- A data-driven, stochastic prediction framework for risk assessments is needed involving extensive modelling of all involved components, risk assessment and scenario mining using AIS data.

Important limitations & boundary conditions:

The establishment of risk criteria for traffic encounters, cargo and vessel safety are weakly defined given the complexity and multitude of operation environments.
The sharing of experience on scenario mining and assessment is crucial for a rapid and feasible certification process.

Milestone code E: Human aided full open water navigational decision support at speed in all weather & traffic conditions

ALFUS autonomy level: 4
Current TRL: 6/7

Relevance for the path to autonomous shipping:
For ALFUS level 4 on decision making, further value is added to autonomous and highly automated ships through enabling short term decision making in traffic conflict solutions for vessel encounters in more dense traffic and environmentally more extreme conditions. The vessels are sailing at sufficient speed to effectively keep the vessel on its pre-set track. The system raises safety levels as it timely alerts and explains proposed decisions by indicating the level of risk involved for cargo, vessel and close and more complex traffic encounters. It timely alerts if pre-set schedules are not kept or fuel consumption is over budget. The ALFUS 4 level uses the risk indicators to maximize the systems share in the decision making. The known intentions of some of the vessel encounters lowers the traffic risk.

Description of added value per use case:
The short term decision making at speed enables sailing through dense traffic areas and structured, often route committed areas. Survey vessels can use it for their transit operations when to cross dense traffic lanes. All other use cases can use it in a manned level 4 situation. The application of this level of shared decision making increases the off-time of the watch keeping and increases the level of safety on cargo, vessel and traffic encounters in addition to a more efficient fuel operation.

Required development steps:
The technology isn't available today (TRL 6/7). System development requires:

- the accumulated modelling of the Rules of the Road to assess their proper application and demonstrate good seamanship to reflect current traffic solution practice and responses to extreme weather,
- to assess the risk levels and identify criteria to verify the decision making,
- the capability to share & confirm own & target vessels' intentions,
- improvements on Human factors (MMI) concerning the presentation of decision alternatives and explaining capabilities,
- Artificial Intelligence based upon extended ship-to ship & shore communication, environment and vessel behaviour modelling can further enhance the short term (collision avoidance) decision making.
- The development is needed of a certification assessment framework for continuous verification & validation of decision tools (equivalent safety).
- A data-driven, stochastic prediction framework for risk assessments are needed (extensive modelling of all involved components, risk assessment and scenario mining using AIS data.

Important limitations & boundary conditions:
See Milestone code C. In ambiguous multiple vessel scenarios with known track intentions an overarching vessel traffic management function is needed. Again this rises legal issues.

Milestone code F : Human supervised decision support at all speeds in all weather & traffic conditions.

ALFUS autonomy level: 5
Current TRL: 5/6

Relevance for the path to autonomous shipping:

In addition to the level 4 on the decision support in open waters at speed, level 5 adds capability for the slow speed operations in all weather and local, complex traffic conditions. This decision capability extends the autonomous operations into restricted waters, ports and rivers and enables low speed open water operations (anchoring, people or cargo transfer at sea, extreme weather handling) and extends the level of autonomy.

Description of added value per use case:

The decision support capability at low speeds enables sailing through more dense traffic areas in very restricted areas and includes ship-to-ship or ship-to-object operations. All other use cases can use it in a manned level 4 situation. The added value for all use cases comes with the further extension of the off-watchkeeping time and increased safety of operation.

Required development steps:

The technology isn't available today (TRL 6/7). System development requires:

- the accumulated modelling of the local rules of the road to assess their proper application and demonstrate good pilot capability reflecting local practice, using shared target vessels' predicted tracks and responding to momentaneous communication & VTM interaction,
- to assess the local risk level and identify safety criteria to verify the decision making,
- to develop autonomous ship-ship(tug) interaction and ship-infrastructure interaction models,
- improvements on Human factors (MMI) concerning the presentation of decision alternatives and explaining capabilities,
- Artificial Intelligence based upon extended ship-to ship & shore communication, environment and vessel behaviour modelling can further enhance the short term (collision avoidance) decision making,
- the certification framework requires a significant extension with the incorporation of the tug interacting capability, the highly specific environment (infrastructural & climates) and local ports and inland waters ruling.

Important limitations & boundary conditions:

Specified levels of Situational awareness and nearby sensor modelling. The proximity operation requires other sensors and generally higher situational refreshing rates. Ship design adjustments facilitating low speed manoeuvring and well-defined procedures for tug assistance interaction.

3.3 Domain/aspect: Acting

G) Human directed all-weather track prediction & keeping capability at speed
H) Human aided, all-weather track prediction & keeping capability at speed
I) Human aided, all-weather accurate track prediction & keeping capability at speed

Operational Alignment							
		ALFUS autonomy level applied to the system level					
		0	1	2	3	4	5
Use case	1						
					G	**H**	
	2						
							I
					H		
	3						
							I
				H	**H**		
	4						
					G	**G**	**H**

Milestone code G: Human directed all-weather track prediction & keeping capability at speed.

ALFUS autonomy level: 3
Current TRL: 9

Relevance for the path to autonomous shipping:
An all-weather track prediction and keeping capability with sufficient accuracy at speed is a prerequisite from level 2 onwards autonomous sailing. The longer periods of unattended ship sailing requires a track prediction tools which incorporates the effects of wind, waves and current through a schedule and fuel consumption prediction and self-learning track and schedule keeping system.

Description of added value per use case:
Prerequisite for the all use cases. Apart from the necessity for the other steps within the control loop to be effective, the track and schedule keeping adds directly to easing the tasks of the officers of the watch and saves the traditional helmsman.

Required development steps:
- the development of more accurate service margins as to better predict potential speed loss in more harsh conditions due to wind and waves,
- the development of AI based systems which identify contributions to the speed loss due to (local, temporarily) current, fouling, diverging draft &trim.

Important limitations & boundary conditions:
Acting capabilities require ship specific analysis based upon the ship specific propulsion and manoeuvring configuration.

Milestone code H: Human aided, all-weather track prediction & keeping capability at speed.

ALFUS autonomy level: 3/4
Current TRL: 8/9

Relevance for the path to autonomous shipping:
An all-weather track prediction and keeping capability at speed is a prerequisite for level 4 autonomous sailing. It is capable of using alternative or reduced manoeuvring means to execute the proposed track and assess the efficiency of the alternative manoeuvres.
Dealing with the more close quarter encounters requires a more accurate modelling of manoeuvring in waves, it enables a more safe and effective use of space during multiple vessel encounters.

Description of added value per use case:
Prerequisite for the all use cases, with the exception of the small survey & surveillance vessel which can do with a lower level 3 implementation.

Required development steps:
The development of accurate vessel manoeuvring models both for the own ship operating in waves (using more detailed data) and for the other vessels (using little data).

Important limitations & boundary conditions:
Acting capabilities require ship specific analysis based upon the ship specific propulsion and manoeuvring configuration.

Milestone code I: Human supervised all weather accurate track prediction & keeping capability at all speeds

ALFUS autonomy level: 5
Current TRL: 7/8

Relevance for the path to autonomous shipping:
An all-weather more accurate track prediction and keeping capability at all speeds is a prerequisite for level 5 autonomous sailing. The acting capability include the ship board safety assessment of crew and cargo given the proposed execution of the mission at all speeds. It is capable of using alternative or reduced manoeuvring means to execute the proposed track or manoeuvre and assess the efficiency of the alternative manoeuvres. It extends the capability to execute complex low speed operations using multiple (external) propulsors.

Description of added value per use case:
Prerequisite for the all use cases at level 5.

Required development steps:
- Highly sophisticated, accurate propulsion and manoeuvring prediction models accounting for multiple non-linear interactions with assisting vessels and infrastructure and allocating multiple propulsors,
- the development of accurate vessel manoeuvring models both for the own ship operating in shallow water and current gradients and for the other vessels.

Important limitations & boundary conditions:
Acting capabilities require ship specific analysis based upon the ship specific propulsion and manoeuvring configuration.

4. Crew tasks & ship design

There is a strong desire to reduce the size of the crew on ships with increasing levels of autonomy. Since the crew currently performs a vital role in the day-to-day running of the ship, the removal of crewmembers will lead to changes in the functionality that the ship itself can provide. For this analysis, the changes have been subdivided into two main categories: 'main machinery' and 'miscellaneous crew tasks'.

4.1 Domain/aspect: Main Machinery

The main machinery on autonomous ships will be different from the typical propulsion plant. The reason for this is that the current systems require underway maintenance and repairs. Advances will, therefore, have to be made to enable reliable operation of the ship's main machinery without human attendance for prolonged periods of time. The steps that can be taken to achieve this do not only benefit autonomous ships but can also add value for conventional ships.

Within this category, the following milestones are identified:

A) Advanced remote condition monitoring
B) Condition-based maintenance
C) Increased reliability, availability, maintainability & safety through redundancy
D) Battery power
E) Fuel cell power

The current TRL per use case and the ALFUS levels at which these milestones add value are presented in this table. Below the table, a more elaborate description of each milestone is provided.

Current (2019) TRL Status per combination of Use Case and Autonomy Level							
Main machinery							
		ALFUS autonomy level applied to the system level					
		0	1	2	3	4	5
Use case	1						
		D,E	**D,E**	**D,E**	**D,E**	**D,E**	**D,E**
		C	**C**	**C**	**A,B,C**	**A,B,C**	**A,B,C**
	2						
		D, E	**D, E**	**D, E**	**D, E**	**D, E**	**D, E**
		C, E	**C, E**	**C, E**	**A,B,C**	**A,B,C**	**A,B,C**
	3						
		D, E	**D, E**	**D, E**	**D, E**	**D, E**	**D, E**
		C, E	**C, E**	**C, E**	**A,B,C**	**A,B,C**	**A,B,C**
	4						
		D, E	**D, E**	**D, E**	**D, E**	**D, E**	**D, E**
		C, E	**C, E**	**C, E**	**A,B,C**	**A,B,C**	**A,B,C**

Milestone code A: Advanced (remote) condition monitoring

ALFUS autonomy level: 3
Current TRL: 8/9

Relevance for the path to autonomous shipping:
Advanced remote condition monitoring is a prerequisite for autonomous ships without an engineering crew. Abnormalities have to be detected and diagnosed well before they can become problems because there will be nobody on board to physically remedy them if they occur.

Description of added value per use case:
Advanced remote monitoring can also be used on conventional ships to increase insight in the performance of the ship's systems, to improve the reliability of operations and to reduce downtime. This is especially important for ships with relatively long missions and short and/or unpredictable port calls. The added value is, therefore, expected to be relevant for all defined use cases.

Required development steps:
The technology is available today (TRL 9) but developing a suitable monitoring system for a given ship and figuring out subsystem-relevant parameters to monitor will still require an engineering effort.

Important limitations & boundary conditions:
Installing an advanced monitoring system will require a significant investment, which gets larger as the number and/or complexity of systems on board increases.

Milestone code B: Condition-based maintenance

ALFUS autonomy level: 3
Current TRL: 8/9

Relevance for the path to autonomous shipping:
Autonomous ships without an engineering crew cannot be maintained in the current way, i.e. mainly while underway. It is, therefore important to understand which maintenance tasks need to be executed when, so the timing of the maintenance can be matched with port calls and the maintenance effort is minimized. This requires knowledge of the condition of the various components.

Description of added value per use case:
Condition-based maintenance (CBM) should reduce the maintenance workload, prevent unnecessary part replacements and reduce the number of failures, thereby reducing maintenance costs and increasing reliability. The added value is, therefore, expected to occur for all use cases.

Required development steps:
Condition-based maintenance requires more detailed operational knowledge about systems and components than is typically available today. Once the monitoring that is required for this is in place, still time will still be required to gather and analyse data and to develop suitable maintenance strategies. This value-adding milestone will, therefore, probably occur one to several years after the implementation of advanced monitoring This implies that CBM can be implemented today for several components, but for a whole ship some development steps need to be taken.

Important limitations & boundary conditions:
Installing an advanced monitoring system will require a significant investment, which gets larger as the number and/or complexity of systems on board increases.

Milestone code C: Increased reliability, availability maintainability and safety through redundancy

ALFUS autonomy level: 0
Current TRL: 9

Relevance for the path to autonomous shipping:
Since there is still no cheap and highly energy dense alternative for the internal combustion engine powered by a liquid diesel-like fuel, the internal combustion engine, with all its maintenance and failure-related challenges should still be considered an important option to power autonomous ships. Since it is unlikely that they will undergo a major technological leap that reduces the number of failures, especially unmanned ships powered by ICEs should have a redundant system with e.g. by incorporating them in a diesel-electric system with multiple generators, a power take-in on the propeller shaft or multiple propulsion lines. Since it is likely that ICE's will stay and use new fuels the usual maintenance and repair issues will stay with them (and perhaps increase).

Description of added value per use case:
More built-in redundancy reduces downtime and increases reliability, also for conventional manned ships. This is deemed relevant for all defined use cases

Required development steps:
The technology is already at TRL 9, so implementation is a fairly straightforward engineering task. Properly quantifying the benefits of increased redundancy may require some additional research.

Important limitations & boundary conditions:
Redundancy typically comes at a cost, in terms of investment cost, maintenance costs and, possibly, system efficiency. It should, therefore, be investigated to which extent it harms the business case of a given autonomous ship.

Milestone code D: Battery-power

ALFUS autonomy level: 0
Current TRL: 6-9

Relevance for the path to autonomous shipping:
Under the assumption that fully autonomous ships are unmanned, they require machinery with a very low maintenance requirement and failure rate. An option that is currently considered is the use of power sources with minimal moving/rotating (i.e. failure-prone) components. Batteries form such a power source and are considered for demonstrators like Yara Birkeland and DNVGL's ReVolt.

Description of added value per use case:
Battery-based systems may significantly reduce maintenance requirements and failure rates, thus reducing maintenance costs, increasing reliability and reducing emissions (if energy is generated sustainably). This is valid for all use cases, although the practical applicability of batteries may be limited for use cases 1, 2 and 4, i.e. ocean crossing cargo ships, short sea ships and wind park support, due to the low energy density of batteries. For super yachts, battery applications for hotel load seem more plausible than for main propulsion, again due to their low energy density. In that

case, batteries can replace parts of the auxiliaries and be a contribution to improved reliability and redundancy (availability).

Required development steps:
Lead-acid and Li-Ion batteries are at TRL 9, but energy density that makes batteries a viable solution for high-power and high-energy ships appears to be at a very low TRL level.

Important limitations & boundary conditions:
Due to the low energy density of present-day batteries, which is 5-10% of that of MDO, practical applications will be limited to auxiliary power and/or ships with a limited amount of installed power and a low endurance. The absence of charging facilities in most ports is currently also an issue that will slow down implementation.

Milestone code E: Fuel cell power

ALFUS autonomy level: 0
Current TRL: 6-8

Relevance for the path to autonomous shipping:
Like the batteries described under D, fuel cells may provide power without internal combustion or many moving components, thus enabling unattended operation. Additionally, hydrogen or a hydrogen carrier can in some forms provide much denser energy storage than batteries, making it more suitable for mid-range power and endurance requirements.

Description of added value per use case:
Fuel cells may significantly reduce maintenance requirements and failure rates, thus reducing maintenance costs, increasing reliability and reducing emissions (if energy hydrogen is generated sustainably). This is valid for all use cases, although especially for use case 1 (ocean crossing), required space for fuel storage may still be an issue.

Required development steps:
Fuel cell technology for maritime applications is at TRL8, but several methods that enable high-energy-density storage of hydrogen are at lower TRL levels (approx 6). Implementing high-powered fuel cells on commercial ships still needs to be done and further work on hydrogen storage is needed to improve practical application of the technology.

Important limitations & boundary conditions:
Insufficient maturity of efficient storage of hydrogen and the absence refuelling facilities will, for now, limit application to smaller ships that frequently call at a port with refuelling facilities.

4.2 Domain/aspect: Miscellaneous crew tasks

Apart from the monitoring, maintenance and repair of the main machinery, a ship's crew performs a host of other tasks, e.g. mooring, general upkeep, administration etc.. When the crew is removed, alternative solutions need to be implemented. The related defined milestones are:

F) Automated mooring
G) Increased shore support
H) Moving responsibilities to shore
I) Moving administrative tasks to shore
J) Simplification of the ship design

The current TRL per use case and the ALFUS levels at which these milestones add value are presented in this table. Below the table, a more elaborate description of each milestone is provided.

Current (2019) TRL Status per combination of Use Case and Autonomy Level							
Miscellaneous crew tasks applied to the system level							
		ALFUS autonomy level					
		0	1	2	3	4	5
Use case	1						
		G,H,I	**G,H,I,J**	**G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**
	2						
		G,H,I	**G,H,I,J**	**G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**
	3						
		G,H,I	**G,H,I,J**	**G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**
	4						
		G,H,I	**G,H,I,J**	**G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**	**F,G,H,I,J**

Milestone code F: Automated mooring

ALFUS autonomy level: 3
Current TRL: 9

Relevance for the path to autonomous shipping:
Under the assumption that autonomous ships are unmanned, they will need to moor themselves. This implies the classic system where ropes are thrown by a person will no longer work. An automated mooring system is, therefore, required.

Description of added value per use case:
The system enables removal of a crew task, which only actually adds value (i.e. saves cost) if all other tasks of these crew members can either also be removed or taken over by other crew members. It is, therefore, unlikely to be a stand-alone value adding measure. This is valid for all use cases

Required development steps:
The system is commercially available today. It is, however, expensive, so implementation would benefit from a development that reduces costs of the system.

Important limitations & boundary conditions:
Given the high cost of the existing automated mooring systems, real value adding applications is likely to be limited to services that call at a limited number of dedicated terminals in combination with ships that have a strongly reduced crew. Today, automated mooring systems are mainly used for ferries with a short pendulum service where frequent and fast mooring at a limited number of berths is required.

Milestone code G : Increased shore support

ALFUS autonomy level: 3
Current TRL: 9

Relevance for the path to autonomous shipping:
In the quest to remove crew members from a ship, it was found that for a lot of tasks, automation of the task does not seem to be the most favourable solution. Executing tasks like inspection, maintenance and general upkeep by a shore-based crew seems a potentially cheaper, simpler and more effective solution. Increased shore support can, therefore, be an important enabler for competitive autonomous shipping

Description of added value per use case:
Increased shore support enables removal of several crew tasks, which only actually adds value of all other tasks of these crew members can either also be removed or taken over by other crew members. The added value can also be cost reduction and/or increase in quality of maintenance and repair tasks if the shore-based engineering crews include system specialists instead of general engineers that can work on all systems. Such dedicated engineers that visit a large number of ships are already used for selected systems by e.g. Alfa Laval. This applies to all use cases.

Required development steps:
Does not require significant technological breakthroughs but the actual way of realising it, the associated costs and the resulting business cases for various types of ships and operations still need to be elaborated, developed and implemented.

Important limitations & boundary conditions:
Shore-side support is most efficient if it can always be executed at the same location(s) and if sufficient work can be provided for the staff. Ships with 'common' machinery that operate on fixed routes, therefore, are likely to benefit most and should be considered the backbone clientele for a shore support network.

Milestone code H: Moving responsibilities to shore

ALFUS autonomy level: 0
Current TRL: 8

Relevance for the path to autonomous shipping:
Currently, it is stated in law that the person who is responsible for the ship is assumed to be on board. Moving this responsibility to shore is a prerequisite for fully autonomous shipping.

Description of added value per use case:
In practice a captain (i.e. the responsible person) spends the vast majority of his/her time performing tasks that can also be done by a less costly crewmember. Therefore, if the responsibility

for a number of ships can be taken over by a single person on shore, this enables cost reduction. The added value of the solution is likely to apply to all use cases.

Required development steps:
A change in regulations is required as well as the development of shore-based infrastructure that provides the responsible person with a sufficiently rich overview of the status of the ship to enable him/her to actually take the responsibility. Both issues may take a significant amount of time to achieve.

Important limitations & boundary conditions:
The added value will be most significant if a single person on shore can take over responsibility for multiple ships, so operators with a significant fleet will benefit most.

Milestone code I: Moving administrative tasks to shore

ALFUS autonomy level: 0
Current TRL: 9

Relevance for the path to autonomous shipping:
Current crews perform a significant number of administrative tasks on board. For the operation of autonomous (unmanned) ships, these tasks should be executed on shore, since there will be nobody on board to do them.

Description of added value per use case:
Moving administrative tasks to shore reduces the, usually very high, workload of a ship's crew, thus improving working conditions. Centralized handling of administrative tasks for multiple ships can also improve efficiency and quality of these tasks. This applies to all use cases.

Required development steps:
There are no technological impediments, apart from any technology to gather the required data that is now gathered by the crew.

Important limitations & boundary conditions:
The milestone will probably add most value if the total administrative workload is enough to occupy a person for a large part of his/her workweek, so centralized administrative task handling for multiple ships is likely to be preferred.

Milestone code J: Simplification of the ship design

ALFUS autonomy level: 1
Current TRL: 8/9

Relevance for the path to autonomous shipping:
If fully unmanned autonomous ships arrive, they can be made simpler and cheaper by removing unnecessary aspects and components. This includes removal of obvious ships volumes and items like accommodation, life support and lifesaving appliances, but may also lead to more fundamental simplifications in the design due to the removal of risk to persons on board. This may e.g. lead to reconsideration of e.g. SOLAS regulations.

Description of added value per use case:
If ALL people can be removed from a ship, the abovementioned simplifications and cost savings can be realised. This limits the added value to use cases 1 - 3 since the wind park support ships (use case 4) are specifically designed to carry people.

Required development steps:
There is no technology development required, but the regulatory changes that are required to enable significant simplification of the design are significant and far from trivial. Well-founded regulation changes will require a large research effort.

Important limitations & boundary conditions:
The largest benefits of this milestone can only be achieved after the international (IMO) regulations are changed.

5. Collection, processing and communication of data

JIP AS WP4 'Collection, processing and communication of data' has focussed on determining a method for identifying and collecting the necessary data and processing it into information about the condition of vessel, environment and systems. This involves the data required to assess the status of ship and systems in normal operations, in degradation of systems, malfunctions and calamities, but also the data involved in remote control actions. The data to assess the environment of the ship also needs to be assessed under normal conditions with optimal conditions for all sensors and in case of malfunctions (sensors and communication), calamities and all scenario conditions (e.g. high traffic density, extreme weather and sea state conditions, not COLREGS compliant vessel behaviour).

The value adding milestones as output of the work in WP4 is organized in the following domains/aspects

- Situational Awareness
- Equivalent Safety in Situations of Complexity and Uncertainty
- Operational Alignment
- Communications

5.1 Domain/aspect: Situational Awareness

The basics of autonomous and unmanned shipping is in automating the decision-making processes (e.g. on navigation) that are currently being made by the human crew on board. An essential basis for automating the decision-making processes is formed by adequate situational awareness (SA) of the system. SA is the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status. SA applies to various aspects of Autonomous Shipping:

- SA for sailing an autonomous ship, including guidance, navigation and control.
- SA for 'health monitoring' the autonomous operations, including the ship's internal systems, the ICT-systems, (incl. communication) (cyber)security and contingency planning.

The following milestones are distinguished in the domain 'Situational Awareness':
A – Adequate sensing systems for external situational awareness under all conditions
B – Co-operative information sharing support services, including e-Navigation providing advanced understanding of future states
C – Multi-sensor fusion for autonomous assessment of the external situation under extreme conditions and scenario complexity

D – Autonomous contingency awareness, through 'Health Monitoring' of the technical systems and the understanding of the external conditions and scenario complexity.

Situational Awareness							
		ALFUS autonomy level applied to the ship level					
		0	1	2	3	4	5
Use case	1				**D**	**D**	**D**
							C
					A,B,C	**A,B,C**	**A,B**
	2				**D**	**D**	**B,C,D**
					B,C	**B,C**	**C**
					A	**A**	**A**
	3				**B,C,D**	**B,C,D**	**B,C,D**
						A	**A**
					A		
	4				**D**	**D**	**B,C,D**
					B,C	**B,C**	**C**
					A	**A**	**A**

Milestone code A: Adequate sensing systems for external situational awareness

ALFUS autonomy level: 3
Current TRL: 7

Relevance for the path to autonomous shipping:
Sufficient and adequate sensors for SA of the external ship are key in providing the complete and accurate external operational picture for navigation, collision avoidance and special manoeuvres (e.g. mooring).

Description of added value per use case:
Advanced sensing systems can also be used on conventional ships for decision support to the crew members on navigation in complex situations and in early detection of potentially dangerous situations. For manned shipping, the added value is, therefore, expected to be relevant for especially the use case 2 (short sea shipping) and use case 3 (shipping in inland waters & port approaches). For autonomous and unmanned shipping, the added value is for all defined use cases.

Required development steps:
The standard sensor suite onboard the traditional ship will provide the regulatory required situational awareness complemented with the human operators sensing and cognitive abilities on the bridge, to support the ship Master and OOW (Officer of the Watch) on the bridge in their tasks.

On traditional ships, the OOW Officer of the Watch, responsible for "Lookout" function, will use human perception means which will need to be covered by additional sensors in case of autonomous or unmanned ships. For autonomous and unmanned shipping, the sensors onboard will need to be complemented with additional camera's, LIDARS and radar systems for specific observation tasks directly around the ship and long-range details (that are currently observed by humans with binoculars). The installation of additional EO/IR camera system and additional radars for measuring distance from bow and stern to the quay will cover the majority of the perception requirements.

Currently the bridge of a manned ship is located high above the water. It can be imagined that a high mast or tethered drone can provide an even higher observation point. When the context allows (e.g. not in situations of high seas or heavy winds), here a tethered drone at few hundred meters altitude above the vessel could even provide "top view control" observation perspective.
The human auditive (sound), odour (smell) sensing and motion (pose, vibration, speed) sensing and cognitive sensemaking (comprehension) and projection abilities used in Situational Awareness on board the ship will need to be replicated for information not provided by other (multi-) sensor systems.

Important limitations & boundary conditions:
Installing an advanced set of sensors for external situational awareness should be augmented with

- An adequate sensor fusion solution to provide an integrated, complete, consistent and comprehensive external situational picture, suitable for automation of decision making on navigation, collision avoidance and special maneuvers.
- Added analysis and intelligence algorithms to autonomously create the recognized and predicted maritime operational picture, i.e. the 'projection' level of future states, as required for autonomous navigation decision making.
- A presentation and visualization methodology to prevent (remote) operators from information overload and just/right-in-time alerting.

Milestone code B: Co-operative Information Sharing Support Services, including e-Navigation

ALFUS autonomy level: 3
Current TRL: 4

Relevance for the path to autonomous shipping:
For the Situational Awareness of the external environment, the data inputs are to an ever larger extent being provided digitally from data sources and information services that are external to the autonomous or unmanned ship. This may include:

- External navigation support services, such as VTS, ECDIS charts, AIS, VDES, …,
- Meteorological info.
- Communication with nearby ships and (off)shore installations, including both audio/voice and data communication.
- External roles requiring access to the ship and its autonomous shipping functions over its Rendez-Vous Control Unit (RCU, e.g. for piloting, tugging or emergency interventions).

Together with the ship's own systems for assessing the external situational awareness, they are key in complementing and increasing accuracy of external operational picture for safe navigation, collision avoidance and special manoeuvres (e.g. mooring).

Description of added value per use case:
For autonomous and unmanned shipping, the added value is for all defined use cases.

Required development steps:

- Development of standards for the three types of data inputs as described in the previous paragraphs.
- Implementation and roll-out of the required external services to provide this information.

For a long period of time, autonomous and unmanned ships have to take into account and communicate with systems and ships that are not optimally prepared for autonomous operations yet. As such, alternative systems and processes have to be supported for operating in a hybrid autonomous and traditional shipping environment.

Important limitations & boundary conditions:
Boundary conditions for autonomous 'Co-operative Information Sharing Support Services, include:
- Standardization of (external) information services, processes, communication protocols and data formats.
- Sufficient and adequate support and uptake for providing these services.

Milestone code C: Multi-sensor fusion for autonomous assessment of the external situation

ALFUS autonomy level: 3
Current TRL: 4

Relevance for the path to autonomous shipping:
Effective sensor fusion is essential for onboard reasoning, sense making and decision making. Heterogenous multi-sensor fusion increases system robustness and reliability and broadens the sensing capabilities.

Description of added value per use case:
As with the sensing systems themselves, sensor fusion can also be used on conventional ships for improved decision support to the crew members. For autonomous and unmanned shipping, the added value is for all defined use cases.

In addition, the total amount of sensor data and extracted information for Situational Awareness grows quickly when multiple sensors with high resolution and update rates are used. Transmission of large amounts of such source data over (low-capacity and costly) satellite transmission will lead to high costs. Hence, sensor fusion is needed to reduce the amount and send only the needed part of the data to human operators and as such can help to reduce the required transmission capacity.

Required development steps:
The sensors onboard the traditional ship are not always digitally connected with automatic processing units, in which the data and detections and tracks can be fused and shared as information. The automatic processing for comprehension and projection will require further development and integration for autonomous ship situational awareness. The most challenging for autonomous ships is the autonomous processing of the sensor data and autonomously creating the recognized and predicted maritime operational picture, i.e. the level-3 'projection' level of future states, including its visualization by means of an adequate (e.g. humanly 'manageable') human-machine interface.

To reduce satellite bandwidth requirements, sensor fusion can be used to derive combined figures generated from multiple heterogenous sensors. This is, however, on-going research and thus bit rate estimates may change according to obtained knowledge in near future.

Important limitations & boundary conditions:
Boundary conditions for accurate data fusion, include:
- Sufficient and adequate sensors for SA of the external ship under all conditions and scenarios are key in providing the complete and accurate external operational picture for navigation, collision avoidance and special manoeuvres (e.g. mooring).
- Standardisation of data formats and sensor interfaces for unambiguous interpretation and ease of integration.

Milestone code D: Autonomous contingency awareness, through 'Health Monitoring' of the technical systems and the understanding of the external conditions and scenario complexity.

ALFUS autonomy level: 3
Current TRL: 2

Relevance for the path to autonomous shipping:
At all moments, it is essential for autonomous shipping the have an up-to-date assessment on the technical status of its internal systems (including ship integrity and status, machinery, sensing systems and the ICT monitoring, communications and decision making systems) to be aware whether the ships technical systems are still capable to operate autonomously and to assess complexities and uncertainties in the onboard conditions and the direct environment of the own ship that may impact is correct and reliable autonomous operations. On its outcome and perceived uncertainties in the current operational status and the 'complexity of the external situation', an autonomous or unmanned ships ship can take informed decisions on whether it can autonomously handle the current situation at the requested level of autonomy, or whether it has to switch from an autonomous operating modus to (e.g.) a remote controlled or even fail-to-safe modus of operations.

Description of added value per use case:
For autonomous and unmanned shipping, the added value is for all defined use cases.

Required development steps:
Risk mitigation is a key element for operating autonomous and unmanned ships by shipping companies. Highly reliable autonomous decision-making and supporting functions are therefore required. Nevertheless, full hundred percent certainty on the autonomous decisions made onboard under all conditions and in all external situations/contexts may appear to be an utopia. Hence, the overall system design for autonomous and unmanned shipping should be based on the principle of 'design-for-uncertainty', in which the situations are detected that are on or beyond the boundaries of the design limits of the autonomous decision-making functions and for which mitigation measures are provided in the form of enabling the transition / switch from an autonomous shipping operational modus to another operational mode (such as a remote controlled or a failsafe operational modus).

Such a risk mitigation strategy requires from the system developers that the various autonomous systems and supporting contingency modules have the appropriate levels of self-awareness on the reliability level and the quality/trustworthiness of the data provided, and from the shipping companies it requires that the autonomous or unmanned ships are integrated with / embedded in the overarching operations infrastructure together with a Shore Control Centre.

To support such a risk mitigation approach based on the principle of 'design-for-uncertainty' for autonomous and unmanned shipping, the following development steps should be addressed:

- Additional and improved sensing systems are required that continuously monitor the essential on-board technical systems, including ship integrity and status, machinery, sensing systems and the ICT monitoring and decision making systems.
- Reliable and quantitative data is required on the reliability and accuracy of the data so that an overall and reliable picture of the ships internal operations status can be made.
- A methodological approach (including root cause analysis) is required for merging, integrating, assessing and acting upon the multitude of data sources and sensing systems.

Important limitations & boundary conditions:
Boundary conditions for autonomous 'Autonomous Contingency Awareness', include:

- Guidelines (e.g. by authorities and/or classification organizations) on assessing equivalent safety levels, related to the aspect of autonomous 'Autonomous Contingency Awareness' for the internal ships systems.
- Adequate technical systems for autonomous 'Autonomous Contingency Awareness' need to be developed as described in the previous paragraph.

5.2 Domain/aspect: Operational Alignment

The following milestones are distinguished in the domain 'Operational Alignment':
A - Agreed upon / standardised autonomous navigation and operations process model for business process interoperability between ship, shore and other stakeholders.
B - Agreed upon / standardised functional system decomposition for technical interoperability.
C - Agreed upon / standardised (common) data model for technical interoperability.

Operational Alignment							
		ALFUS autonomy level applied to the ship level					
		0	1	2	3	4	5
Use case	1				B,C	B,C	A,B,C
	2				B,C	B,C	A,B,C
	3				B,C	B,C	A,B,C
	4				B,C	B,C	A,B,C

Milestone code: A: Agreed upon / standardised autonomous navigation and operations process model for business process interoperability between ship, shore and other stakeholders.

ALFUS autonomy level: 5
Current TRL: 2

Relevance for the path to autonomous shipping:
Wide-scale adoption of maritime autonomous and unmanned shipping can be enormously facilitated and stimulated with an aligned, accepted and preferably agreed upon (standardized) overarching business process framework and operations map, i.e. a shared blueprint for (re-)designing the operations processes, for defining the supporting functional capabilities, for structuring the task allocation process to identify those tasks that can and those that (currently) cannot be allocated to software modules and as basis for defining the data models needed for the

overall system design[2]. The business process framework and operations map overarchi the various stakeholders (ship, shore and other stakeholders such as transport companies and suppliers) as part of for instance a logistics are passenger transport process. The main merits include:

- it provides a validated, complete and shared blueprint for (re-)designing the operational processes and for identifying all functions and tasks for autonomous and unmanned shipping,
- it guides the task (re-)allocation process to either autonomous systems or to human operators,
- it enables interoperability between (sub-)systems and thereby reduces the costs of integration,
- it forms the basis for a structured information model supporting system interconnectivity, and
- it provides a blueprint for operational process and runtime use case (re-)design.

Description of added value per use case:
The added value is mainly in the use cases for large scale adoption of autonomous and unmanned shipping, i.e. in which a multitude of larger ships and interoperating stakeholders will be involved. This will to a larger extend be for the use cases 1 and 2.

Required development steps:
The development steps are mainly related to making agreed upon standards on the functional decomposition in a global context. The introduction may be spurred through the involvement of early adopters, e.g. through the adoption by major, trend-setting, stakeholders in the maritime shipping arena. Initial field labs can test the viability and issues with deploying the functional decomposition, both internally within organizations and across organizations. The international shipping community (e.g. as organized within the IMO) may play a leading role.

Important limitations & boundary conditions:
Limitations can be foreseen in:

- A slow international standardisation process
- Low (business) interest in standardisation by a few dominant players

Milestone code B: Agreed upon / standardised functional system decomposition for technical interoperability

ALFUS autonomy level: 3
Current TRL: 3

Relevance for the path to autonomous shipping:
A standardized functional system decomposition of the technical systems will reduce integration cost through improved system interoperability and prevent from supplier lock-in. It will stimulate the development of (partial) technical solutions for autonomous or unmanned shipping as their interoperability with other suppliers' solutions can more easily be realized. In addition, it forms the basis for a structured information model supporting system interconnectivity and supports the blueprint for operational process and runtime use case (re-)design. As such, tor autonomous and

[2] H. Bastiaansen, E. (Elena) Lazovik, E den Breejen, J. van den Broek, 'A Business Process Framework and Operations Map for Maritime Autonomous and Unmanned Shipping: MAUSOM', MTEC International Conference on Maritime Autonomous Surface Ships (MTEC/ICMASS), Trondheim, Norway, on 13th – 14th November 2019, in: Journal of Physics – Conference Series, Volume 1357, 2019. https://iopscience.iop.org/article/10.1088/1742-6596/1357/1/012017.

unmanned shipping the added value is especially in lowering the costs for both development and deployment and lowering the barriers to participate and develop solutions.

Description of added value per use case:
The added value is mainly in the use cases for large scale adoption of autonomous and unmanned shipping, i.e. in which a multitude of larger ships and interoperating stakeholders will be involved. This will to a larger extend be for the use cases 1 and 2.

Required development steps:
The development steps are mainly related to making agreed upon standards on the functional decomposition in a global context. The introduction may be spurred through the involvement of early adopters, e.g. through the adoption by major, trendsetting, stakeholders in the maritime shipping arena. Initial field labs can test the viability and issues with deploying the functional decomposition, both internally within organizations and across organizations. The international shipping community (e.g. as organized within the IMO) should play a leading role.

Important limitations & boundary conditions:
Limitations can be foreseen in:

- A slow international standardisation process
- Low (business) interest in standardisation by a few dominant players

Milestone code C: Agreed upon / standardised (common) data model for technical interoperability

ALFUS autonomy level: 3
Current TRL: 3

Relevance for the path to autonomous shipping:
As with the functional decomposition, the common data model forms the basis for system interoperability. As such, it is key lowering integration costs of technical solutions and interoperability in the overarching business process framework.

Description of added value per use case:
The added value is mainly in the use cases for large scale adoption of autonomous and unmanned shipping, i.e. in which a multitude of larger ships and interoperating stakeholders will be involved. This will to a larger extend be for the use cases B and C.

Required development steps:
The development steps are mainly related to making agreed upon standards.

Important limitations & boundary conditions:
Limitations can be foreseen in:

- A slow international standardisation process
- Low (business) interest in standardisation by a few dominant players

5.3 Domain/aspect: Communications

The following milestones are distinguished in the domain 'Communications:
A - Automated connectivity and (multi-)path selection
B - Bandwidth availability, including adequate service contracts
C - Ship-to-ship voice communications

Communications							
		ALFUS autonomy level applied to the ship level					
		0	1	2	3	4	5
Use case	1				**B**	**B**	
					C	**C**	**B,C**
							A
	2				**B,C**	**B,C**	**C**
							B
							A
	3				**C**	**C**	**C**
					B	**B**	**A,B**
	4				**B,C**	**B,C**	**C**
							B
							A

Milestone code A: Milestone title: Automated connectivity and (multi-)path selection

ALFUS autonomy level: 5
Current TRL: 9

Relevance for the path to autonomous shipping:

The data connection between the ship and the shore consists of a (secure, encrypted) tunnel / VPN-connection between the ship's and the shores firewall over one of the connectivity network options that at a specific moment are available, e.g. satellite, radio or terrestrial (4G/5G, WiFi, …) connectivity. As the communication link is essential for autonomous or unmanned shipping, automatic (re-)configuration of the best available data connection (i.e. automated (multi-)path selection) has an essential role to play in fulfilling two requirements:

- Automatic path selection, in which the most optimal IP-path will be selected for communication, e.g. by optimising the transmission costs against available bandwidth.
- Automatic connection fail-over, in which automatic failover to a secondary (back-up) connection occurs in case of malfunctioning of a primary connection, including both the encrypted data (VPN-) tunnel.

Description of added value per use case:
For autonomous and unmanned shipping the added value is especially essential for those use cases in which intensive communications to the outside world (e.g. between ship and shore) is required, i.e. the use case 2, 3 and 4. For safety reasons, however, also for use case 1 it is essential.

Required development steps:
The technology for automated (multi-)path selection is mature on state-of-the-art IP routers. It is available and already being operationally deployed in other contexts.

Important limitations & boundary conditions:
Non-identified at this moment

Milestone code B: Bandwidth availability, including adequate service contracts

ALFUS autonomy level: 3
Current TRL: 5

Relevance for the path to autonomous shipping:
For the major part of its routes, an autonomous, unmanned or remotely controlled ship will be dependent on satellite services for its communication link to the shore control centre. To ensure high reliability, the ship needs to have two independent communication channels, preferably based on different frequencies and systems.

Description of added value per use case:
For autonomous and unmanned shipping, the added value is of added value for all use cases.

Required development steps:
Current state-of-the-art development maritime satellite communications systems indicate a rapid increase of capacity and lowering costs of satellite services for maritime shipping. The 3 to-10 Mbps connectivity that these satellite services provide are within the range of the required data transmission capacity for autonomous navigation.

Important limitations & boundary conditions:
Although the required satellite capacities for autonomous navigation are becoming available, it is to be realized that these high-end satellite services are (still) very expensive. Moreover, they are usually charged at a 'flat rate', i.e. the customers pay for the level of committed bandwidth that they subscribe to, independent of the actual usage of the bandwidth. For autonomous navigation, this is disadvantageous as in normal operations (hopefully the bulk of the time) the bandwidth requirements are far below the committed values that need to be subscribed to. Hence an appropriate service offering and pricing scheme for maritime satellite services for autonomous or unmanned shipping is needed.

Milestone code C: Ship-to-ship voice communications

ALFUS autonomy level: 3
Current TRL: 6

Relevance for the path to autonomous shipping:
To interact with non-autonomous ships, a 'voice' interface is needed for an autonomous or unmanned ship, which is able to respond to "voice-calls". In case the autonomous ships voice interaction system is not able to autonomously to respond to an incoming voice call, the call is redirected to a human operator, e.g. in the shore control center.

Description of added value per use case:
For autonomous and unmanned shipping, the added value is for all use cases.

Required development steps:
Autonomous voice interaction systems are currently already being deployed in other sectors and contexts. Hence, the basic technology exists, and may be customized for autonomous shipping solutions. Development steps include:

- Agreeing / standardizing a joint vocabulary for maritime voice communications.
- Security mechanisms to protect the voice-communications in maritime, autonomous shipping, context; e.g. on anti-spoofing.

Important limitations & boundary conditions:
Non-identified at this moment.

6. Equivalent Safety in Situations of Complexity and Uncertainty

For autonomous and unmanned shipping to be legally allowed and accepted by society, it is required that its safety level is equivalent to conventional ships, even in (navigation) situations of high shipping complexity and/or uncertainty due to environmental or system health conditions. This implies that the risks for autonomous ships are similar to conventional ships, with the risks transferred from crew to sensors, software and communication systems.
This requires a (continuous) testing and certification process based upon evolving and emerging scenarios including 'mixed' traffic scenarios.

The following milestones are distinguished in the domain 'Equivalent Safety in Situations of Complexity and Uncertainty':
A – Agreed upon equivalent safety assessment and certification process and requirements, including for ship – shore operating modi.
B – Safety scenario extraction and validation

		Equivalent Safety in Situations of Complexity and Uncertainty					
		ALFUS autonomy level applied to the ship level					
		0	1	2	3	4	5
Use case	1				A,B	A,B	A,B
	2				A,B	A,B	A,B
	3				A	A	A
	4				A,B	A,B	A,B

Milestone code A: Agreed upon equivalent safety assessment and certification process and requirements, including for ship – shore operating modi

ALFUS autonomy level: 3
Current TRL: 2

Relevance for the path to autonomous shipping:
To support on-board decision-making for the autonomous or unmanned ship in situations with increased levels of uncertainty or complexity, the autonomous ship needs the capabilities to assess the current risk status and to react adequately in cases of increased (projected) risk levels. This is referred to as the 'contingency planning' capability. The 'contingency planning' capability allows the autonomous ship to understand (complexities and/or uncertainties in) the onboard conditions and the direct environment of the own ship. On the outcome of the assessment of the current and predicted complexities and/or uncertainties, an autonomous or unmanned ships ship can take informed decisions on whether it can autonomously handle the current situation at the requested level of autonomy, or whether it has to switch from an autonomous operating modus to (e.g.) a remote controlled or even fail-to-safe modus of operations.

Hence, the equivalent safety of an autonomous or unmanned ship is not only determined by the autonomous ship itself, it also includes the ship's capability to adequately switch between operating modi and their safety levels. Therefore, this might also include the safety levels of the (combined ship and) shore operations processes.

In such a variety of ship-and-shore operation modi, the equivalent safety assessment and certification of the technical implementations in combination with the operations processes is very difficult. However, its adoption, the methodology and criteria how this will be assessed is of great importance. It allows ship builders and solution providers to develop their systems to be eligible for certification. It requires to be a continuous process given the permanently evolving technology and operational scenarios.

To interact with non-autonomous ships, a 'voice' interface is needed for an autonomous or unmanned ship.

Description of added value per use case:
For autonomous and unmanned shipping, the milestone is of added value for all use cases.

Required development steps:
Development steps include agreeing / standardising upon an equivalent safety assessment and certification process and requirements suitable for a continuous application within a permanently evolving operational context.

Important limitations & boundary conditions:
Standardization of an equivalent safety assessment and certification process and requirements in an international global context (e.g. through IMO?) may be a long-term process.

Milestone code B: Safety scenario extraction and validation

ALFUS autonomy level: 3
Current TRL: 3

Relevance for the path to autonomous shipping:
For ship manufacturers to ensure that new autonomous or unmanned ships will operate at the required (equivalent) safety levels, intensive testing is required. For maritime (autonomous) shipping, this is not feasible with actually making sufficient shipping mileage and situations. Hence, to optimize testing and validation efforts and at the same time ensuring that the maritime ships will be safe, new 'scenario-based verification and validation' simulation approaches help to overcome these challenges. The continuous character of this process requires an automated AI based scenario generation tooling.
Training sets for such AI tools can be acquired from AIS data for specific areas (e.g. a busy junction in a traffic separation scheme) and specific situations (e.g. crossing at the bow or stern of a stay-on vessel). By studying parameters such as distance and pose at CPA, both normal and more extreme encounter situations can be detected from AIS data, and can be used for validation. The relevant scenarios per use cases are further to be defined using (sets of) the relevant AIS situations. Reference [30531-4-MSCN, 2020. WP3] represents a study into this AIS based situation analysis.

Description of added value per use case:
For autonomous and unmanned shipping, the added value is especially for all the use cases at the higher ALFUS levels where autonomous navigation decisions are made, i.e. level 3 and higher.

Required development steps:

Safety scenario extraction and validation is currently already being developed and deployed for autonomous driving contexts. Hence, the basic conceptual methodologies and tooling exist. However, to what extent the methodology can also be applied for autonomous and unmanned shipping has to be assessed. Development steps include:

- Assessing the feasibility of (current) safety scenario extraction and validation methodology for the autonomous shipping contexts.
- Assessing whether available data on current shipping scenario's is sufficient to validate the extracted autonomous shipping scenario's, e.g. the data from the (historic) AIS databases. Can the current shipping scenarios be found in AIS data. And if so, can it be detected automatically? Common scenarios can be found in AIS, and so much data is available on historical decisions to either pass at the stern or the bow of a stay-on ship, as well as the maintained distances to those ships and the time at which ships start to anticipate the situation. For more specific scenarios, for example with multiple ships where a particular ship makes a particular manoeuver that the other ships must react on, the number of situations where this has actually occurred, will be much lower. And most importantly, these situations will be harder to detect from AIS automatically. On the other hand, going through cases with extreme parameters in AIS data will most likely also provide new scenarios that were not foreseen yet.

Important limitations & boundary conditions:

Positive results of the outcome of the development steps listed above. In particular the validity of the simulation based approach, using AI selected scenarios, to certify the safety of the continuous evolving automation context is a serious challenge.

Literature on ALFUS Framework

[1] Autonomy Levels for Unmanned Systems, (ALFUS) Framework, Volume I: Terminology Version 2.0, 2008.

[2] AUTONOMY LEVELS FOR UNMANNED SYSTEMS (ALFUS) FRAMEWORK, Volume II: Framework Models, Version 1.0, 2007.

[3] AUTONOMY LEVELS FOR UNMANNED SYSTEMS (ALFUS), Power Point Presentation