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Disclaimer

Executive summary

The shift from manned to unmanned and autonomous navigation raises fundamental questions on how operational processes should be structured in order to ensure the safety of future shipping. Coming from today's conventional shipping, existing activities and processes used for navigation have been recorded, mapped and adopted to the requirements of the MUNIN concept.

Following an introduction, the framework for the Autonomous Bridge System is outlined to connect it to the MUNIN concept's architecture and to show this deliverable's scope and its boundaries. Within chapter three, present manned ship operation is analyzed, taking into account technology, information requirements, legal framework, processes and responsibilities. The fourth chapter derives activities from current ship operation, identifies and classifies them to be able to draw a conclusion for the process redesign within this deliverable. Subsequently, a process map for autonomous navigation is established in chapter five and corresponding requirements for the Advanced Sensor System and the Autonomous Ship Controller are listed in the following chapter. Within chapter seven, the interfaces to the Shore Control Center and the Engine Automation System are explained. Finally, the research needs for the further development of the MUNIN concept for autonomous navigation are described in the eighth chapter. Also, possible solutions to meet the previously defined requirements are reviewed therein.

List of abbreviations

ABS	Autonomous Bridge System
ACCSEAS	Accessibility for Shipping, Efficiency Advantages and Sustainability
AEMC	Autonomous Engine Monitoring and Control
AIS	Automatic Identification System
ASC	Autonomous Ship Controller
ASS	Advanced Sensor System
BAS	Bridge Automation System
CCTV	Closed-Circuit Television
CDEM	Construction, Design, Equipment and Manning
Chayka	*Seagull* (Russian terrestrial radio navigation system)
COLREG	International Regulations for Preventing Collisions at Sea
CoG	Course over Ground
CPA	Closest Point of Approach
DGPS	Differential Global Positioning System
DSC	Digital Selective Calling
EAS	Engine Automation System
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive Economic Zone
eLORAN	Enhanced Long Range Navigation
ENC	Electronic Navigational Chart
EOT	Engine Order Telegraph
EPIRB	Emergency Position-Indicating Radio Beacon
ETA	Estimated Time of Arrival
FtS	Fail-to-Safe
GHz	Gigahertz
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System

GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
HF	High Frequency
IAMSAR	International Aeronautical and Maritime Search and Rescue Manual
ICS	International Chamber of Shipping
INS	Integrated Navigation System
IMO	International Maritime Organization
LAN	Local Area Network
LDC	London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter
LLC	International Convention on Load Lines
LORAN	Long Range Navigation
MARPOL	International Convention for the Prevention of Pollution from Ships
MF	Medium Frequency
MLC	Maritime Labour Convention of the International Labour Organization
MMSI	Maritime Mobile Service Identity
MONALISA	Motorways and Electronic Navigation by Intelligence at Sea
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
NAVTEX	Navigational Telex
OOW	Officer of Watch
PiLoNav	Precise and Integer Localization and Navigation in Rail and Inlandwater Traffic
PiW	Person in Water
PoC	Port of Call
RoT	Rate of Turn
RPC	Remote Procedure Call
RpM	Revolutions per Minute
SAR	Search and Rescue
SART	Search and Rescue Transponder
SCC	Shore Control Center

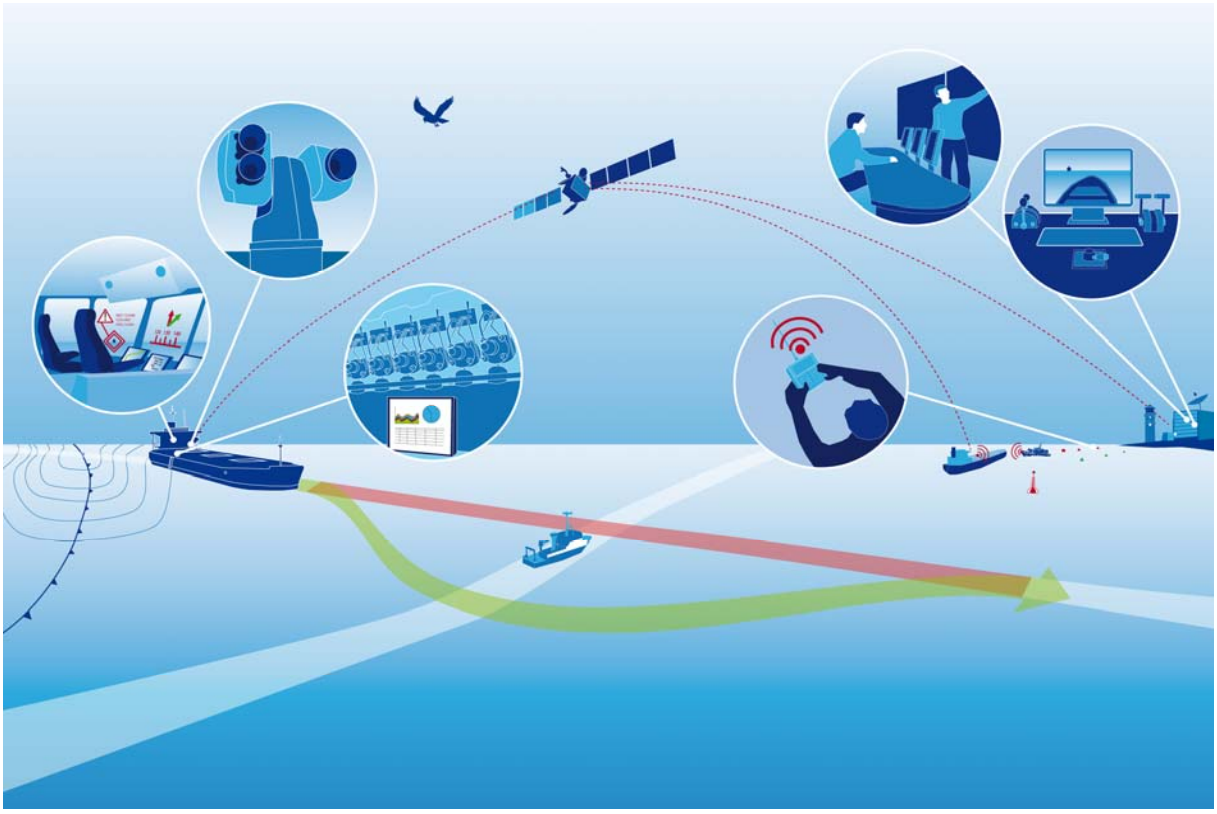
SDME	Speed and Distance Measuring Equipment
SoG	Speed over Ground
SOLAS	International Convention on the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TCPA	Time to Closest Point of Approach
THD	Transmitting Heading Device
TSS	Traffic Separation Scheme
UAS	Unmanned Autonomous Ship
UKC	Under-Keel Clearance
UNCLOS	United Nations Convention on the Law of the Sea
UTC	Coordinated Universal Time
VHF	Very High Frequency
VSAT	Very Small Aperture Terminal
VTS	Vessel Traffic Services
XTE	Cross Track Error

Table of contents

1. Introduction

Based on the activities and requirements for navigation which have been presented and developed further at the MUNIN consortium meeting in Reykjavik in March 2013 a process map has been established. In accordance with the project's vision to contribute to the enhancement of safety in conventional shipping, the starting point for this deliverable's results is to be found in today's conventional ship operations. By keeping close to existing processes a transfer of individual elements of the project's anticipated outcome into manned shipping shall be eased and necessary legal adjustments reduced to a minimum.

Besides the elaboration of the process map itself, a focus has been put to fit it well into the architecture concept for unmanned and autonomous shipping and to ensure smooth interface connections between the Autonomous Bridge System ABS, the Engine Automation System EAS and the Shore Control Center SCC. Below picture illustrates in a simplified way the interrelationship of all components of an unmanned and autonomous ship according to the concept of the MUNIN project.



This document represents the first integral layout for bridge processes from restructuring the task of ship navigation for unmanned and autonomous deep sea voyages. In an upcoming deliverable this topic will be further investigated to constitute D5.4 Autonomous deep sea navigation system concept.

2. Framework for the Autonomous Bridge System

The ABS constitutes the central component within the concept for the autonomous ship which is responsible for all navigation-related matters.

To enable the operation of a completely unmanned and truly autonomous bridge, strong and direct connections to the other components onboard and ashore are necessary. Each one of these components form part in replacing an onboard human information provider and decision maker. In conventional shipping, even with the most advanced and comprehensive equipment, the OOW still acts as the sole true system integrator. The MUNIN concept now aims to shift this function to an autonomous ship controller which is being supervised and supported by a manned shoreside control station. The first and major requirement in the development towards autonomy is the improvement of data availability and quality. An Advanced Sensor System will be able to produce resilient information about the current situation of the ship. The Engine Automation System EAS will ensure smooth operation of technical installations related to propulsion plant and steering gear. Existing bridge functionalities will be adopted to fit into a Bridge Automation System BAS as an ABS support component. These mentioned modules are all directly interlinked with each other, the Autonomous Ship Controller ASC and the SCC by satellite connection.

The content of this deliverable is limited to deep sea navigation only and does consider neither operations such as pilotage or berthing nor navigation within a TSS or a narrow channel. Interfaces of the ABS to the SCC and the EAS are described in autonomous operation mode only, while the functionalities of those components with no direct relation to navigation are not covered.

Information from D4.3 Evaluation of ship to shore communication links and D4.4 Initial interface description are respected to fit the remapped processes well into the MUNIN architecture also with regard to limitations for communication. Furthermore, reference is made to D5.1 Legal and liability analysis for automated navigational systems in order to reduce the necessary adjustments in international maritime legislation. To include fall-back solutions within the process redesign, D7.1 Error and human intervention report in the context of autonomous ships has also been accounted for within this paper. Beyond that, it is also intended to give guidance for the transition from this general concept of autonomous navigation to the development of D5.3 Sensor systems for automated detection.

3. As-Is-Analysis of present manned ship operation

3.1 State-of-the-art technology analysis

Position measurement

Since the introduction of satellite navigation for civil use, GNSS has changed the face of navigation. Reliable position data is ever since available on every spot of the planet's surface. GPS receivers which are in use on present day merchant ships work with an accuracy of 10 to 20 meters on the open sea and DGPS with the correction of landbased reference stations with an accuracy of 3 to 10 meters. Advanced GNSS receivers are able to process signals from both GPS and GLONASS. As of now these are the only two satellite navigation systems that have been approved by IMO and thus neither the Chinese Compass-system nor the European Galileo-system will be examined further within this paper.

The use of GNSS devices is the most preferred method of producing valid position data. Both GPS and GLONASS offer worldwide coverage at a sufficient position data quality.

To be prepared for a malfunction of these GNSS devices, other means to determine the ship's position have to be available.

Radio navigation systems such as LORAN or Chayka could represent a valid alternative to GNSS, if it wouldn't be for their limited regional availability. Firstly, the range from the shore side stations is limited to several hundred nautical miles extending from shore. Secondly, the future of radio navigation appears to be uncertain due to the fact that originally some countries have announced to discontinue their service while others are enhancing the system further towards eLORAN. This limits the usability of the system considerably and is another reason why currently only a limited number of ships carry radio navigation devices at all. This is a very unfavorable fact due to the system's high reliability, accuracy and immunity against many kinds of interferences.

Another means of positioning commonly used on manned ships is celestial navigation. Whether an automated sextant will be a utilizable method for positioning needs to be further examined within the project. In coastal areas, terrestrial navigation is also a suitable method for positioning. As another tool of choice, the technique of dead reckoning can always be employed. This method of navigation uses the last known position and the speed over elapsed time and course to calculate the current position. This method of navigation has been used for a long time and is in use today within many inertial navigation systems and produces surprisingly accurate position data.

Heading measurement

Every ship is equipped with a gyro compass and a magnetic compass to indicate the ship's heading. The gyro compass is used as the principle compass on board, mainly for its high accuracy and low likeliness of breakdown. The magnetic compass may appear to be a relic from another age. Yet actually, it is still in use because of its robustness and its complete independence from electric power supply. Both of these compass types have the disadvantage of relatively low course accuracy during heavy sea or intense maneuvering so that the displayed heading can't be precisely relied upon for navigation under these specific circumstances. A more advanced alternative can be satellite compasses, which basically consist of a set of integrated GNSS-sensors. Beyond only providing the ship's heading these devices are also capable of indicating the ship's RoT as well as pitch, roll, heave and position information, of course. Another option, producing the most accurate heading information, is the fiber-optic compass. As a mere electronic rotation rate sensor it is almost free of wear and maintenance during its service life. Modern but only rarely used multi-compass systems consist of a combination of the above mentioned systems and combine their advantages to produce a more accurate reading for the ship's heading.

Depth measurement

The echo sounding devices which are in use in commercial shipping measure the vertical depth below the ship's keel by means of acoustic sound waves. The current and past depth contour is displayed with a possible error in accuracy of approximately 2.5 % of the measured depth which ranges up to 1500 meters. A threshold can be set so that a depth alarm will sound in case the pre-selected depth contour is underrun. For a very limited number of coastal sea areas there are also draft information systems available, which calculate the ship's under-keel clearance from the ship's draft, detailed bathymetric charts and real time water levels from shore gauge stations. Similar systems can also be used on a number of coastal shipping routes to benefit from tidal streams in order to save bunker.

Speed and distance measurement

The ship's voyage speed can be determined by four different measurement devices. A hydromechanic speed log measures the ahead-speed through water by the pressure at an impact tube with the major disadvantage that this tube gets easily clogged. A less error-prone method for speed measurement through water is by an electromagnetic log, where voltage is being induced between a probe and a pair of electrodes to determine the speed through water. The most commonly used device is a Doppler-log, which measures the speed over ground by means of sonar waves up to a water depth of 600 meters. At higher depths, the speed through water can be determined. Both methods operate regularly with an error in accuracy of approximately 0.5 % to 1.0 % of the measured speed while significantly larger inaccuracies can be experienced. The more advanced Doppler-logs are able to display ahead-, astern and transverse speed, RoT and also water depth. In addition, the speed over ground can easily be calculated by any automatic positioning appliance. The distances sailed can easily be calculated from this known speed over time.

Track pilot

On today's ships the steering control can easily be automated to a great extent. Modern track control autopilots are able to precisely follow the course over ground laid out by the voyage plan with deviations of only about half of the ship's breadth. Furthermore, through self-tuning adoption many steering parameters are determined by the system itself. The ship's loading characteristics and the indirect steering effect of the ship's propeller are accounted for and the effects of wind, sea state and current are compensated. Through the rudder actuating values the permissible rate of turn and the radius of turn can be set. Also, steering criteria can be chosen between precise steering to minimize XTE and eco-steering to minimize fuel consumption. Some applications also offer an extensive feature to adjust the voyage speed according to a designated arrival time at a defined way point.

AIS

The use of AIS-transceivers has had a major impact on the safety of shipping. Information about as many as 500 targets within a range of up to 30 nm has become easily available. The device transmits and receives data about a ship's name, type, size, status, position, heading, speed, cargo, next port of call as well as its IMO- and MMSI-number via VHF radio. The data is either fixed input, needs to be entered manually or originates directly from the ship's sensors. Due to the fact that the displayed data's accuracy and reliability can't be assessed, AIS is accredited as an aid to navigation only.

Radar/ARPA

The most proven method to detect and monitor objects is by the use of radar which works through the emission and reception of electromagnetic impulses. Merchant ships are always equipped with one short pulse X-band antenna for high resolution and one long pulse S-band antenna for high range. Both of them operate with an error in accuracy of no more than 1.0 % of their current working range or 30 meters at the most. The radar picture is than being processed by the ARPA function to continuously and automatically plot the acquired targets to determine distances and bearings towards that object. Also, the object's speed, course and position can be calculated, if the corresponding own ship data is available. Radar/ARPA devices are subject to certain errors through either false echoes caused by multiple echo reflection, by extraneous radar waves or by false input data from own ship sensors. Certain X-band radar-based wave and surface measurement technology can be used for ocean surface monitoring as well.

ECDIS/INS

The vast majority of merchant ships which travel the oceans nowadays are obliged to be fitted with an ECDIS. The performance capabilities vary to some degree, depending on the manufacturer and the age of the application. But all of them must generally be able to fully replace paper charts on a ship's bridge as a two-unit-installation. The navigation information system displays digital navigable sea charts and offers the possibility for integration of nautical publications. Furthermore, sensor data from AIS, echo sounder, GNSS, NAVTEX, radar/ARPA can also be interfaced with the system and displayed on the screen. Each input data value originates from one single predefined source and is not counterchecked against data from redundant sensors for probability. That's why the OOW still remains the only true system integrator on the ship's bridge. Beyond the provision of information, an ECDIS allows for all features of conventional chart work and

also assists in voyage planning and passage monitoring. Additionally, the system offers a log book function and a navigational alarm management system.
The most evolved holistic approaches to further develop an ECDIS towards MUNIN's aim of an autonomous bridge system are integrated navigation systems. These Integrated Navigation Systems INS promote safety of navigation by enabling a centralized access to all available navigational information and by monitoring the quality of data and processes. Through reference points for the positions of antennae and sensors within a consistent common reference system reliable calculation of standardized data for e.g. time, position, heading and speed can be carried out. In case there are several sources for the same value these are being processed to determine one resilient value to be distributed throughout the system. This kind of data fusing improves the quality of the information produced and the output of the following processes being used. In addition, INS' are able to combine various tasks, functions, sensors and systems on the ship's bridge and enable full data access to the user via a single interface. A certain degree of redundancy within the sensors ensures that all necessary data can be acquired by a number of independently working sensors.

VDR

A Voyage Data Recorder gathers and stores all available information about the own ship's status, position and movement as well as all sounds from within the wheelhouse and from voice radio. The recorded data of at least the past twelve hours is kept within a retrievable unit to be used for future analysis in case of an incident and must therefore be secured against any attempts of tampering. The VDR must be equipped with an emergency power supply to be able to operate even in case of blackout for at least 2 hours.

Telecommunication

All means of maritime telecommunication are part of the Global Maritime Distress and Safety System which is based on both radio and satellite communication devices. DSC radiotelephony operates on VHF, MF and HF and is used for the transmission and reception of voice radio, distress alert and distress relay messages. Also, mobile VHF devices are in use for voice radio communication, while radiotelex transceivers for written communication and NAVTEX receivers for navigational and meteorological warnings operate on MF and HF. Satellite communication via Inmarsat devices allows for the reception of NAVTEX-messages outside of radio range and of SafetyNET-messages. Additionally, voice telephony, transmission and reception of text messages via telefax, telex and e-mail are provided. Many of these GMDSS elements can also be used for distress alerting while EPIRB and SART are installed on board for that sole purpose only. /1/2/

3.2 Information requirements

The operational requirements for the different technical devices listed below are set by the IMO as the competent international body.

Satellite navigation

The use of a GNSS receiver is mandatory on board of all ships irrespective of their size. /3/ A Global Navigation Satellite System is a satellite system that allows to determine a position in latitude and longitude as well as of velocity and time worldwide. The data quality in satellite navigation can be further enhanced by the use of land-based differential correction signals or by the integration of other means of positioning. Such combined receivers have to have a static and a dynamic accuracy within 35 meters in non-differential mode and 10 meters in differential mode while the minimum resolution of position in latitude and longitude is 0.001 minutes. /4/

Radio navigation

LORAN and Chayka are the only two long-range radio navigation systems currently operated and in those sea areas covered they represent a valid alternative to satellite navigation. Their ranges may vary depending on different factors but are said to extent to approximately 1000 nm from the transmitter station at the most. The receivers for either one or for both systems should produce valid position data within 7.5 minutes of being switched on with a position accuracy of 20 to 90 meters. The acquisition of signals, cycle selection and tracking must be fully automatic and produce valid position data at ship speeds of up to 35 kn. /5/ Radio navigation signal availability should exceed 99.8 % in high-traffic areas and 99.5 % in low traffic areas while a 99.85 % service reliability should not be underrun. In coastal areas with dense traffic the accuracy for positional information should be within 10 meters with a 95 % probability at 10 second update rates. In low-traffic open sea areas the error for positional information should not exceed 100 meters with a 95 % probability at 10 second update rates. /6/ An advantage of radio navigation compared to satellite navigation is that the signals don't get distracted as easily and positioning is more precise in e.g. port areas.

Heading measurement

Each ship from 500 gross tonnage upwards must be fitted with two means to determine and display the ship's heading at the main steering position. One of these has to be non-magnetic while the other one has to be independent of any power supply. Usually this requirement is met with the installation of one gyro and one magnetic compass. /7/

A gyro compass is required to point to the direction of the ship's heading in relation to geographic north. In latitudes of up to 60° and at a speed of 20 kn the residual steady state error should not exceed ±0.25° x secant latitude. Under the same circumstances, an error of ±2.0° respectively ±3.0° due to rapid alteration of speed or course should not be exceeded. A divergence in reading between the master compass and its repeaters of up to ±0.5° is permissible. After being switched on, the gyro compass should settle within 6 hours. /8/ A special kind of gyro compass under the same legal provision is the fiber-optic compass.

A magnetic compass is required to point to the direction of the ship's heading in relation to magnetic north. It is bound to seek a certain direction in azimuth, depending on the induced magnetism of the earth and needs proper compensation of residual deviation. The directional error should not exceed ±0.5° on any heading. /9/

Another means for the determination of a ship's true heading is by the use of a THD, e.g. a satellite compass, mandatory for all ships of 300 gross tonnage and upwards. This electronic device operates with thresholds for transmission error of less than ±0.2° and for static error of less than ±1.0° which should not be exceeded. Follow-up error should be less than ±0.5° at turning rates of up to 10° per second and less than ±1.5° at turning rates between 10° and 20° per second, respectively. /10/

Depth measurement

All ships of 300 gross tonnage and upwards shall be fitted with an echo sounding device or another electronic means to measure and display the current under-keel clearance of the ship. /11/ The purpose of echo sounding equipment is to provide reliable information on the depth of water under a ship to aid navigation particularly in shallow waters. At a speed between 0 kn and 30 kn the transducers must be capable to measure any clearance between 2 meters and 200 meters. The sound waves are to be set at a speed of 1500 m/s at a repetition rate between 12 and 36 pulses per minute. Data storage for at least 12 hours has to be assured. The required accuracy in measurement must not fall below ±2.5 % of the indicated depth, respectively not below ±0.5 meters on the 20 meter range nor below ±5.0 meters on the 200 meter range. /12/

Speed and distance measurement

To give an indication of speed and distance made good through water or over ground, each ship of 300 gross tonnage and upwards must be equipped with appropriate measuring equipment. /13/ This SDME must provide forward speed in water depths of more than 3 meters beneath keel. The error in the indicated speed should not exceed 2 % or 0.2 kn whichever is greater, measured without the effects of wind, current and shallow water. The error in the indicated distance should not exceed 2 % or 0,2 nm run by the ship each hour whichever is greater, measured without the effects of wind, current and shallow water. These requirements have to be met at ship movements of up to 10° during rolling and up to 5° during pitching. /14/

Track pilot

All ships of 10000 gross tonnage and beyond are to be equipped with a system to automatically keep a steady heading or to follow a laid out track. /15/This device should enable control of the ship with a minimum operation of its steering gear. Limitations are made by the ship's specific maneuverability and additionally by setting of a permissible rudder angle. The interchange between automatic and manual steering must be possible within 3 seconds. An audible and visual alarm signal will indicate any case of malfunction, power supply failure or if the ship is off track. /16/

AIS

An automatic identification system shall be fitted on all ships of more than 300 gross tonnage engaged in international voyages and on all ships of more than 500 gross tonnage engaged in domestic trades. /17/ It is its purpose to enhance the safety of navigation by automatic data exchange. An AIS-transceiver exchanges static data such as MMSI-#, IMO-#, call sign, name, length, beam, ship type and the location of position fixing antenna on the ship. In addition, dynamic data, such as position with accuracy indication and integrity status, UTC, CoG, SoG, heading, RoT and navigational status is transferred. Except for the latter, all named features are transmitted automatically. Only the navigational status and voyage-related data such as draft, hazardous cargo types, PoC, ETA and waypoints have to be entered manually. Furthermore, the devices enable short safety-related message communication. /18/

Radar

Radar equipment is used to determine and display the range and bearing of radar transponders and of other surface craft, obstructions, buoys, shorelines and navigational marks to assist in navigation and collision avoidance. Ships of a size of more than 300 gross tonnage require one X-band 9 GHz radar, while ships of a size of more than 3000 gross tonnage shall additionally be equipped with an S-band 3 GHz radar as well. Both devices must operate independently of each other. /19/ A radar antenna mounted at a height of 15 meters above sea level must indicate:

- A coastline at 20 nm if the ground rises 60 meters
- A coastline at 7 nm if the ground rises 6 meters
- A surface object at 7 nm if it is a ship of 5000 gross tonnage from any aspect
- A surface object at 3 nm if it is a ship of 10 meters in length
- A surface object at 2 nm if it is an object of 10 square meters

The working range varies between a minimum of 50 meters to at least 32 nm at an accuracy within 30 meters or 1 % of the range scale in use, whichever is the greater. Ship's movement such as pitch and roll of up to 10° may not affect the range performance. An error in accuracy of ±1.0° is permissible for the ship's heading and the provided bearing measurement indicated on the screen. The scan antenna must turn clockwise through 360° at a rate of not less than 12 RpM and be capable to operate satisfactorily in relative wind speed of up to 100 kn. /20/

ARPA

As an additional feature to radar, ships of 300 gross tonnage and upwards are demanded to carry an electronic plotting aid to automatically determine range and bearing of targets to identify a danger of collision. Ships, which are mandatorily fitted with two radars must also carry a second ARPA device. /21/ An automatic radar plotting aid allows for continuous, accurate and rapid situation evaluation and thus reduces the workload of the watchkeeper. The acquisition of targets may either be manual or automatic, while at manual acquisition 10 targets must be processed and 20 targets at automatic acquisition. Target data comprises at least range, bearing, CPA, TCPA, course and speed, displayed in relative and true vectors. A function for trial maneuvers must be provided, capable of simulating the effects of an own maneuver on all targets. /22/

ECDIS

All ships, irrespective of size, shall have nautical charts and publications for route planning and monitoring throughout their voyages. An electronic chart display and information system, which is obliged to be fitted on most ships now anyways, may be accepted as meeting these requirements. /23/ To contribute to the safety of navigation an ECDIS should display all ENC information. Firstly, all permanently retained data, consisting of coastlines, selectable safety contour, isolated dangers and traffic routing systems must be indicated. Secondly, on first display of a chart, its display base, drying line, fixed and floating aids to navigation, waterway boundaries, prohibited and restricted areas, chart scale boundaries and cautionary notes must be indicated as well. Thirdly, spot soundings, submarine cables and pipelines, ferry routes, details on isolated dangers, details on aids to navigation, content of cautionary notes, ENC edition date, geodetic datum, magnetic variation, graticule and place names may be displayed on demand. Furthermore, navigational elements and parameters, such as own ship's primary and secondary track, vector of course and speed, variable range marker, electronic bearing line, event marks, dead reckoning position and time, estimated position and time, position fix, time, tidal streams or currents, danger highlights, clearing line, planned course and speed, waypoints, distance to run and planned positions with date and time may be displayed. Additionally own ship's past data, including time, position, heading and speed, ENC source, edition update history of the previous 12 hours should be stored at one-minute intervals as a kind of log book function. /24/25/

VDR

A Voyage Data Recorder shall be fitted on all merchant vessels of 3000 gross tonnage and above. /26/ Its purpose is to safely store relevant ship information over a period before and after the occurrence of an on-board incident. This data record of at least 12 hours is to be used for subsequent incident investigation. The ship's information contained therein consists of position, speed, heading, bridge and communications audio, radar data, echo sounder, alarms, rudder order and response, engine order and response, hull opening status, watertight and fire door status and optionally also hull stresses, wind speed and acceleration, all appointed with an respective timeframe. /27/

GMDSS

It is the purpose of this internationally agreed upon service to ensure rapid and automated alerting in the event of a maritime distress using several different means of communication. Merchant ships of 300 gross tonnage and more which are engaged in global trades are obliged to fully comply with all of its components. The transmission and reception of distress and safety messages as well as related communication is based on radio and satellite links. The scope of information which is carried by these standardized and automatable distress calls broadcasted by Inmarsat, DSC radiotelephony or EPIRB always contains the ship's MMSI and, if fitted with corresponding equipment, its position. Also, the nature of distress can be chosen manually from being either fire explosion, flooding, collision, grounding, danger of capsizing, sinking, disabled and adrift, person over board, piracy or abandoning vessel. The SART on the other hand is not able to transport such messages and solely responds to X-band radar waves and indicates the transponders positions on the emitting ship's radar screen at a minimum of 7.5 nm distance. /28/

3.3 Legal framework

Maritime law consists of a framework of both national and international regulations governing various aspects related to ship operation. The basic rights and obligations imposed on the states on the one hand and the shipping industry on the other are laid out in international conventions established mostly by the IMO of which COLREG, LDC, LLC, MARPOL, MLC, SOLAS, STCW and UNCLOS are the most pertinent ones. These agreements have been ratified by the signatory states and have thus been transferred into national legislation. The above mentioned regulations can be distinguished as being either:

- Navigational standards,
- Construction, design, equipment and manning standards or
- Pollution prevention standards.

To reduce the likelihood of maritime incidents as well as to minimize the harmful impacts on the environment of such incidents, navigational standards have been established. Such legislation, enforcing rules for collision avoidance and traffic management systems as TSS and VTS can mostly be found within COLREGs and SOLAS chapter V.

The standards for CDEM are related to the quality of ship operation with regard to safety. Regulations for ship design and construction mainly aim to minimize the consequences of incidents for the ships involved and for the marine environment. Equipment standards have a similar aim, also allowing for the monitoring of the fulfillment of other types of standards, e.g. through automatic discharge recording. MARPOL is among the most relevant conventions for these standards, along with LLC, SOLAS chapter II and several further IMO resolutions. Requirements concerning crew training and navigational devices which aim to help to reduce the risk of collisions can mostly be found within STCW. As an evidence that the laid out requirements have been met, certificates will be issued accordingly.

There are two principle kinds of vessel-source marine pollution which must be distinguished. Accidental pollution is the result of maritime incidents, causing environmentally harmful substances to enter into the sea. The second one is operational pollution, caused by intentional discharges, being either compliant or non-compliant with maritime law. The matter of pollution prevention standards is governed mostly by LDC and MARPOL, to a larger extent.

The legal correlation between states and ships derives from the United Nations Convention on the Law of the Sea which determines the guidelines for the utilization and exploitation of the world's marine natural resources. A distinction is made between flag, coastal and port states. The first being the state in whose territory a ship is registered and whose flag it flies and is entitled to fly. The ship is subject to its exclusive legislative and enforcement jurisdiction on the high seas. If a ship operates within the EEZ of state, this state is also considered the coastal state. A port state is a state in whose port a ship is currently present. As the MUNIN project focuses on deep sea voyages these legal considerations will be limited to flag state legislation. In accordance with UNCLOS, a flag state is required to effectively prescribe and enforce the applicable rules and standards on ships of its registry. In this respect, the flag state must ensure that all ships flying its civil ensign fully comply with all IMO conventions the relevant state has ratified. /29/

3.5 Processes and responsibilities

The matrix on the following page has been developed according to specifications laid out by STCW /30/ and ICS /31/ and has been validated by experienced shipping professionals. It illustrates the activities which are conducted on a conventional merchant ship's bridge today along with the assigned role, e.g. persons and technical devices. These activities are divided into groups and explained more in detail in the first two columns on the left. The columns in the middle part show how each person of the bridge team is involved in performing an activity and to what degree:

- R Responsible Responsible in actually performing an activity
- A Accountable Accountable in legal terms for performing an activity
- S Supportive Supportive in performing an activity
- C Consultative Consultative in performing an activity
- I Informed Relevant information to be shared

The columns on the right illustrate how each navigational device is involved in performing an activity and to which degree:

- D Display Display of information
- E Execution Execution of tasks
- P Proposal Proposal for problem-solving

Activity	Role	Master	OOW	Pilot	Lookout	Helmsman	GPS	Compass	Echo-Sounder	Speed Log	ECDIS	Radar / ARPA	AIS	Autopilot	GMDSS / INMARSAT	NAVTEX
Voyage planning																
Apply information from nautical publications and sea charts	Consider adequately the information provided during voyage planning	A	R								D	D				
Obtain required routing information	Gather routing information for the upcoming voyage Calculate permissible freeboard and minimum stability Decide what kind of navigation is most suitable (e.g. rhumb line, great circle or composite sailing)	A	R								D				D	D
Prepare voyage plan	Include planned route and voyage schedule for a complete voyage from berth to berth	A	R				D				P					
Verify voyage plan	Forward the composed voyage plan to the ship's Master for countercheck and approval before entering into force	A / R					D				P					
Determine the required provisions	Calculate, order and store provisions according to the expected duration and conditions of the upcoming voyage	A	R													
Lookout																
Maintain proper lookout by human means	Monitor the ship's environment by sight Monitor the ship's environment by hearing	A	S	C	R											
Maintain proper lookout by other means	Monitor the ship's environment by technical devices	A	R	C	S		D	D	D	D	P	E	D			
Maintain proper radio watch	Monitor GMDSS equipment	A	R	C											E	
Monitor ship's environment	Observe the surrounding of the ship	A	R	C	S			D	D	D	P	E	D			
Monitor traffic situation	Follow traffic movements in ship's vicinity	A	R	C	S						E	E	D			
Determine compass errors	Determine magnetic compass errors Determine gyro compass errors	A	R					D								
Determine the ship's position by more than one method	Use terrestrial navigation to continuously establish the current position of the ship Use celestial navigation to determine the ships position Use technical navigation to continuously establish the current position of the ship	A	R	C	S		E	D	D	D	P	D				
Operate bridge equipment to collect information	Handle all applicable bridge equipment to compile all information required for navigation	A	R	C	S		D	D	D	D	E	E	D	E	D	D
Increase attention in proximity of dangers to navigation	Order an additional lookout to the bridge or to the bridge wings in areas where potential dangers to navigation are reported, expected or detected Use all means for safe navigation	A	R	C	S	S										
Bridge watch																
Handover of bridge watch	Pass all relevant information to relieving officer Ensure fitness of relieving officer	A	R	C	S	S	D	D	D	D	D	D	D	D	D	D
Check bridge equipment	Execute all necessary routine checks and tests of the bridge equipment to ensure operability	A	R													
Employ the approved voyage plan	Observe the track laid out in the voyage plan Adjust the voyage plan if circumstances (safety or security matters, weather conditions, change in destination) require to do	A	R		S	S	D				D	D		E		
Follow the standing order book and the night order book	Observe the written instructions laid out by the ship's Master	A	R		I	I										
Comply with COLREGs	Consider that: "[t]hese rules shall apply to all vessels upon the high seas and in all waters connected therewith navigable by seagoing vessels"	A	R	C	S	S	D	D	D	D	P	P	D	D	D	D
Apply obtained information	Utilize all available information for navigation	A	R	C	I	I	D	D	D	D	D / E	D / E	D	E		D
Operate ship's movement	Handle steering devices Handle propulsion devices	A	R	C		S								E		
Control ship's movement	Monitor ship's position Monitor ship's motion	A	R	C	S	S	E	D	D	D	E	D				
Manage safety and alarm systems	Monitor navigational alarms Monitor other alarms Sound ship's alarms	A	R	I	I	I	D		D		E	E			D	
Maneuvering																
Consider ship's specific characteristics	Account for individual fixed and variable properties	A	R	C		S		D			D		D	E		
Consider the effects of wind and current	Estimate and compensate for direction and force of leeway drift	A	R	C	S	S	D	D		D	D			E		
Consider the venturi effect in shallow or narrow waters	Adapt ship's speed with regard to under keel clearance but stay maneuverable at the same time	A	R	C		S	D	D	D	D	D					
Conduct navigational maneuvers	Consider various conditions for navigational maneuvers (e.g. weather conditions, sea state, water depth, distance to potential dangers and proximity to traffic lanes	A	R	C	S	S	D	D	D	D	P	D			D	
Conduct anchoring maneuvers	Consider various conditions for anchoring maneuvers (e.g. weather conditions, sea state, nature of seabed, water depth, distance to potential dangers, proximity to traffic lanes, length of anchor chain	A	R	C	S	S	D	D	D	D	P	D			D	
Conduct mooring maneuvers	Consider various conditions for mooring maneuvers (e.g. weather conditions, sea state, water depth, distance to potential dangers, proximity to traffic lanes)	A	R	C	S	S	D	D	D	D	P	D			D	
Communication																
Internal	Via intercom Via VHF	A	R												D	
External	Receive messages Interpret messages Transmit messages	A	R	C									E		D	
Administration																
Keeping of bridge log book	Enter data into the bridge log book	A	R		S	S	D	D		D	E					
Keeping the standing order book and the night order	Enter instructions for specific occasion	A / R														
Keeping of further log books	Enter appropriate information into the log books	A	R					D							D	
Check update status of nautical publications and sea charts	Identify the publications and charts needed for the upcoming voyage Check if all updates have been applied according to the latest available issue of the Notices to Mariners	A	R	C							D					
Update status of nautical publications and sea charts	Apply updates according to the latest available issue of the Notices to Mariners	A	R								E					
Emergencies																
Take action in case of a minor incident or failure	Try to resolve the issue by onboard resources, if not successful call for external assistance	A / I	R	C	S	S										
Take action in case of a major incident (own ship in distress)	Evaluate the event Determine whether the event poses a threat to the safety of shipping or to the marine environment Act according to ISM manual and good seamanship Note the event in the logbook and report it to the shipping company as well as to the responsible authority	A / I	R	C	S	S									E	
Assist a ship in distress (other ship in distress)	Acknowledge a received distress call Alter the vessel's course towards the indicated position Establish communication with the ship in distress Provide the required assistance	A / I	R	C	S	S	D	D	D	D	D	D	D	D	D	
Conduct POB-maneuver (own ship's POB)	Execute an appropriate POB-maneuver	A	R	C	S	S	D	D	D	D	P	D	D	E	D	
Participate in search operation (other or own ship's POB	Act according to IAMSAR-manual and MRCC orders	A	R	C	S	S	D	D	D	D	P	D	D	E	D	
Recover a person from the sea (POB rescovery)	Deploy the rescue boat into the water to recover the person from the sea Use other LSA to recover the person from the sea Provide medical care to the rescued person	A / I	R	C	S	S	D	D	D	D	P	D	D			

4. Identification and classification of activities

On the previous page bridge activities have been identified and classified according to the international standards mentioned in the preceding chapter. Now, they are being further investigated on how they can be adopted to meet the requirements imposed by unmanned and autonomous ship operation.

4.1 Activities related to voyage planning

Before commencing an oversea passage, a thorough voyage plan needs to be prepared. On conventional ships, this activity is carried out completely on board. Only in some specific cases data might be required from shoreside information providers. For voyage planning, various routing information has to be gathered and applied from nautical publications and the ship's stability has to be calculated. Also, the required provisions for the upcoming voyage have to be accounted for. From these information, the voyage plan is prepared by the navigational officer and verified by the ship's master.
For an Unmanned and Autonomous Ship UAS it appears to be more practicable to transfer this activity from ship to shore to a large extent. Information gathering and the preparation of the document itself as well as provision calculation will be carried out by SCC operators and as a complete record be transferred to the ship. What will be done on the UAS though, is the part of stability control. In chapters 5.10 and 6.6 the activity redesign will be illustrated further.

4.2 Activities related to lookout

During the conduct of an oversea passage the keeping of a thorough lookout is the main source of information to the navigator. These activities must be performed continuously using visual, acoustic and technical means. This comprises e.g. monitoring of the ship's environmental and traffic situation, keeping a radio watch and determining of the ship's position using methods of terrestrial, celestial and technical navigation. Furthermore, all available bridge devices must be operated correctly to gather information relevant for safe navigation such as heading, speed and under-keel clearance.
This comprehensive set of activities for information gathering must remain on board to the greatest share and requires a considerable redesign for UAS operation. Only voice radio communication will be relayed directly to the SCC while all other activities will be performed independently by the ship's sensors and electronic devices. Several individual processes will be established for individual purposes. Within chapters 5.1 and 6.1 very basic data, such as position, heading, speed and water depth is determined. Chapters 5.6 and 6.4 establish the actual operational status, including the ship's motions and the distribution of masses for example. All weather-related activities will be covered in chapters 5.3 and 6.2, while in chapters 5.13 and 6.8 traffic-related activities are

accumulated. Handling of information from external sources will be outlined in chapter 5.14 for NAVTEX and SafetyNET messages and in chapter 5.16 for AIS messages.

4.3 Activities related to bridge watch

The information which have been gathered in the preceding chapter about lookout activities are required to carry out bridge watch activities. It is the obligation of the OOW to check the bridge equipment for proper functioning and to follow the approved voyage plan and the order books. All available information has to be utilized to ensure the safety of navigation. The ship's movements and maneuvers have to be operated and controlled while all COLREG regulations have to be complied with in all respects. Also, safety and alarm systems have to be monitored and appropriate responses to contingency and emergency situations have to be taken.

Similar to the lookout activities, these activities related to information processing must also be redesigned to stay placed on the ship to the largest proportion. The only exception is that while the on-board mariner could independently decide upon various reasons to deviate from the voyage plan, the UAS would only be allowed to do so after SCC approval. All other bridge watch activities must be carried out by on-board processes to enable truly autonomous navigation. For that purpose the bridge watch will be redesigned and split into various processes. Weather-related input data will be used in chapters 5.4 and 6.3 to conduct weather routing while traffic-related input data will be used in chapters 5.11 and 6.7 to avoid collisions. One point that won't be affected as much by the redesign is steering of the ship. Chapter 5.9 describes the mode of operation of the UAS track pilot. Furthermore, the ship's alarm management is part of the autonomous bridge outlined in chapter 5.15, including emergency handling.

4.4 Activities related to maneuvering

To be aware of the ship's capabilities and limitations when it comes to maneuverability, various factors have to be accounted for. Besides the ship's specific fixed and variable properties, changing external forces and effects have to be identified and compensated, if applicable. On conventional ships this is done mostly by using data from sea trials, by calculating buoyancy and stability and by observing the sea state.

This activity of determining the ship's maneuverability will be divided into two separate processes for UAS operation. Firstly, the dynamics of the ship will be calculated as in chapters 5.7 and 6.5 and will comprise status data from the ship and from the engine. Secondly, characteristic values for buoyancy and stability are calculated as can be seen in chapters 5.10 and 6.6 which are also mostly based on ship status data. Together, these two processes will continuously and very precisely deliver data about the current maneuverability status of the UAS and point out its capabilities and limitations.

4.5 Activities related to communication

Information exchange on a ship can roughly be divided into two groups. On the one hand communication can occur internally between different compartments of the same ship and will either be done by automatic data exchange between interlinked technical devices or by voice telephony or voice radio. External communication between the ship and another sea-based or land-based station on the other hand takes always place either by means of radio or satellite communication. The only exemptions are visual and acoustic distress signals, of course.

To establish a thorough communication structure for the operation of an UAS is one of the key issues of this project. All on-board devices will be linked with a LAN connection to ensure full data availability throughout the ship. For those time periods in which a crew is present on board, a conventional intercom should be fitted additionally. The external communication requires closer attention. As already mentioned in chapter 4.2 all radio communication will be relayed to the SCC and transacted by a human operator. On trans-ocean passages the general information exchange interface between the UAS and the SCC depends on satellite communication. This issue is subject to chapter 7.1 where it will be outlined more in detail. Emergency communication will be the one process deriving from these communication activities. Within chapter 5.15 an approach towards alarm and emergency management will be elaborated which also includes emergency communication. In the event of an emergency a distress call will be submitted directly from the ship using any of its GMDSS means.

4.6 Activities related to administration

From the perspective of many mariners administrative work does consume a lot of their working time on board. Correcting of sea charts and other nautical publications, filling out of checklists and log books, updating of ship and crew certification and keeping up with information demands from shoreside stakeholders are just some of the examples.

As an UAS will obviously make use of an ECDIS it will require weekly ENC-updates which will be submitted by the SCC. Those other administrative activities which can be organized digitally on board will be grouped into chapter 5.2 where a common data base will be created. Depending on the ship's operational status, a certain set of standard information will be submitted in certain intervals to the SCC from this very comprehensive log book. Above that, this data base will be fully accessible to the human operator at all times and also provide a gateway to enter information and to adjust parameters.

4.7 Activities related to emergencies

Any case of emergency poses a potential significant threat to safety and requires high attention from all available on-board resources. Especially on the open seas, ship crews depend very much on their own capabilities for problem-solving as external assistance

is often several days' time away. Upon detection of a situation which might endanger ship safety, the crew has to assess the situation and react to it accordingly, usually accompanied by an alarm of some kind.
The operation of an UAS raises two basic challenges when it comes to emergency handling. In the first step a threatening situation has to be detected and assessed and in a second step it has to be dealt with it. These processes of alarm and emergency management will be mapped in chapters 5.15 and 6.9 as a centralized approach. This redesigned emergency management system will comprise all on-board alarms and be capable to take countermeasures with or without the assistance of the SCC or other external aids. The potential emergency situations span from minor and major technical malfunctions or failures to a full-scale distress situation. Beyond dealing with its own issues the UAS must also be able to assist other ships in distress and to participate in a SAR-operation.

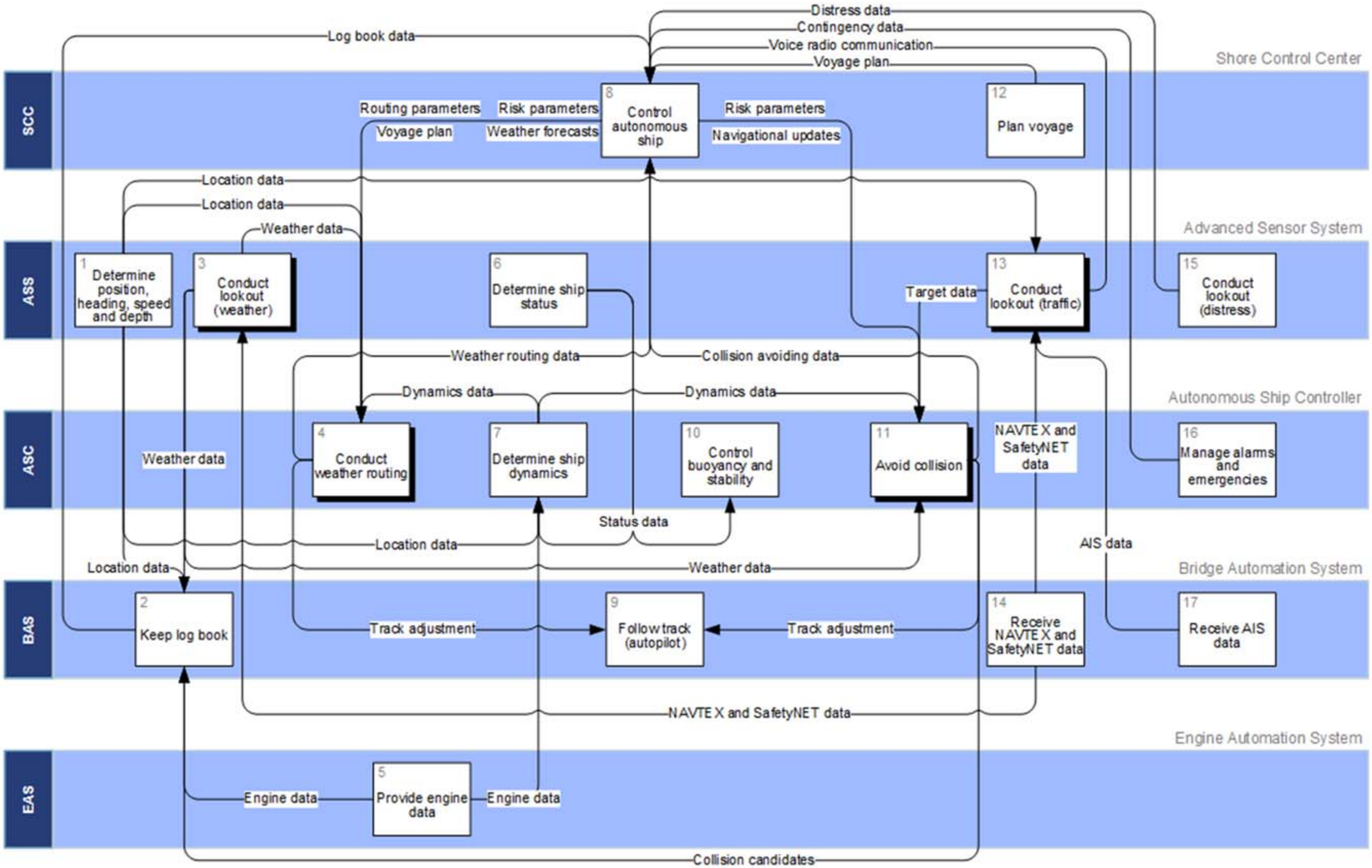
5. Process map for unmanned deep sea ship operation

"How to read"
As the processes being conducted on a ship's bridge are rather complex and depend on various factors, redesigning and mapping has grown quite complex. Here is a short explanation of the process map overview:
The five horizontal bars illustrate systems to which the individual processes, shown as boxes, are attached to. The connections between the processes are linked by arrows. All three object categories are marked with a name to clarify their significance. The process boxes are also consecutively numbered and explained within this very order in the subsequent chapters.
The systems can be distinguished as follows:

- SCC (Shore Control Center): Monitoring and operating of the UAS by land-based and trained professionals
- ASS (Advanced Sensor System): Generating of navigational data by own sensors onboard of the UAS
- ASC (Autonomous Ship Controller): Evaluating of data from own ship sensors onboard the UAS and from shore as well as autonomously operating the UAS
- BAS (Bridge Automation System): Existing holistic bridge system for connection of individual components, also named INS (Integrated Navigation System)
- EAS (Engine Automation System): Corresponding system to the BAS within the engine room on board the UAS

This process map illustrates the requirement specifications for an unmanned ship operating under autonomous mode and conducting a deep-sea voyage from the perspective of the ABS. The requirement specifications have been assigned to certain processes and connections between these processes have been linked. For better clarity not all connections are shown in this overview map. In the following, the processes along with their assigned requirements will be explained, four of them already with an individual process map of their own.

Generally, all data sets processed within the ABS or transmitted to the SCC must indicate a time frame.


Shore Control Center
SCC
Advanced Sensor System
ASS
Autonomous Ship Controller
ASC
Bridge Automation System
BAS
Engine Automation System
EAS
1 Determine position, heading, speed and depth
2 Keep log book
3 Conduct lookout (weather)
4 Conduct weather routing
5 Provide engine data
6 Determine ship status
7 Determine ship dynamics
8 Control autonomous ship
9 Follow track (autopilot)
10 Control buoyancy and stability
11 Avoid collision
12 Plan voyage
13 Conduct lookout (traffic)
14 Receive NAVTEX and SafetyNET data
15 Conduct lookout (distress)
16 Manage alarms and emergencies
17 Receive AIS data
Log book data
Distress data
Contingency data
Voice radio communication
Voyage plan
Routing parameters
Risk parameters
Voyage plan
Weather forecasts
Risk parameters
Navigational updates
Location data
Location data
Weather data
Target data
Weather routing data
Collision avoiding data
Dynamics data
Dynamics data
Weather data
NAVTEX and SafetyNET data
Status data
Location data
AIS data
Location data
Weather data
Track adjustment
Track adjustment
NAVTEX and SafetyNET data
Engine data
Engine data
Collision candidates

5.1 Determine position, heading, speed and depth

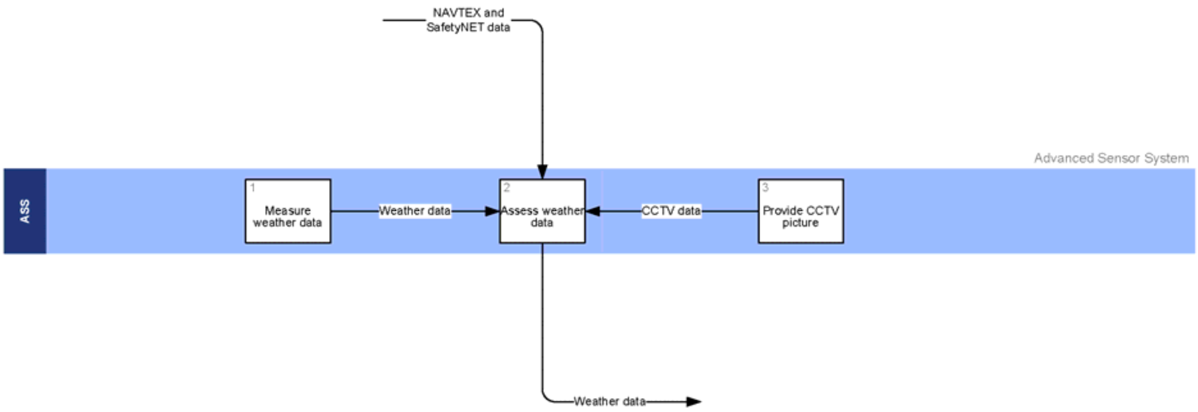
Within this process, navigational data from the ship's own sensors is generated, assessed and fused to be distributed throughout the entire system. As almost all other processes within the ABS depend on these information, referred to as location data, this process is among the most essential for the safe navigation of the unmanned vessel.
The ship's location data, consisting of position, heading, speed and water depth will be provided by sets of redundant on-board sensors.
The main objective of this process lies in evaluating and combining the available sensor data. As already mentioned in chapter 3.1, the sensor technology required to generate the information for this process already exist in multiple versions. The function of this process clearly consists of the so called sensor fusion. The output of all sensors producing the same kind of data must be assessed and combined as only one reference value for each data requirement must be distributed throughout the ABS.
The output will be a resilient set of values which allows to clearly identify the position, heading, speed and UKC of the ship.

5.2 Keep log book

Data from many different ship processes is received by the log book, where it is then stored. What data is regularly submitted to the SCC at what intervals depends on the current UAS control mode. Generally, all log book data can be retrieved directly by the SCC at all times.
Before commencing a voyage, details about the ship's general condition, manning, provision, cargo, draft, voyage plan and the results of stability calculations and of inspections of equipment should be recorded. During the voyage, information about courses steered, distances sailed, positions fixed as well as the state of weather and sea, changes to the voyage plan, embarkations and disembarkations and information about ship routing and reporting systems have to be noted. Special events like incidents relating to possible on-board personnel, malfunction of equipment, potentially hazardous situations, emergencies and distress messages received are also to be registered. Furthermore, all details on operational and administrative matters and those concerning ship safety and security should be recorded.
All of this input data needs to be stored for a minimum of at least 1 year, depending on the requirements of the respective flag state administration. Besides providing a central database the log book process is also responsible to provide sets of data to the SCC.
The composition of data which is submitted from ship to shore in pre-set intervals depends on the current ship status while the SCC can retrieve additional data at any time by individual requests.

System	Obligation	Trigger	Process word	Object	Legal Regulations
The ABS	must	be capable to	receive	all relevant operational data of the ship	STCW A-VIII/2 Part 4-1 (31)
The ABS	must		provide	digital storage for necessary information for all required log books	STCW A-VIII/2 Part 4-1 (31) SOLAS Chapter V R28 (1) IMO Resolution A.916(22)
The ABS	must		transmit	relevant log book information to SCC	SOLAS Chapter V R28 (2)
The ABS	must	offer SCC the possibility to	monitor	relevant operational data remotely	---
The ABS	must/shall	…	…	…	…

5.3 Conduct lookout (weather)



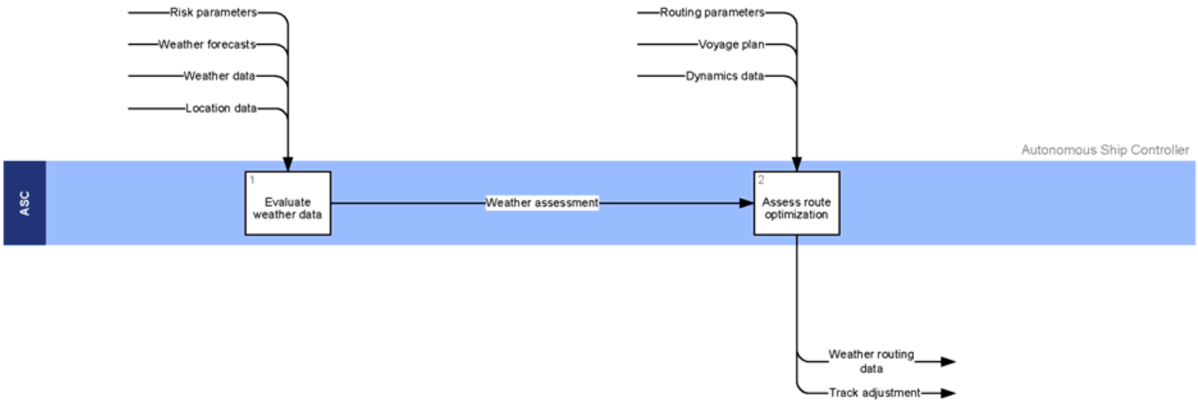
In this process weather observation data is collected by the UAS and the current environmental conditions and their impact on the ship are assessed. This weather assessment is supported by the CCTV picture. The overall view will be used to initiate actions or to notify the SCC.

The process receives input from the UAS weather sensors, other modules in the ABS and the SCC. The main UAS sensor is a conventional weather station, which provides wind direction and speed, precipitation, atmospheric pressure and humidity. The UAS radar will give readings of surrounding rain- or snow showers, in addition to wave height, direction, and period. Furthermore, it will also be used to estimate ocean current and bathymetry in shallow waters. The CCTV system will provide information about the visibility range. From other modules in the ABS this process receives the ship's position, the current route and navigational warnings.

The main objective of this process is to collect, process, verify and output observation of the current and future environmental conditions. Sensor data is collected at different rates and with various degrees of affirmation and correction, thus this process will merge the observations and confirm the correlation of the observations. This will eliminate outliers and statistical noise from the readings and provide a robust representation of the current and future environmental conditions.

The output of this process will be resilient values of the current local weather observations and an improved forecast for the future environmental state placed in a geo-reference system along the planned route. Within this, the process provides notifications of potential environmental threats and vital navigational parameters such as visibility.

5.4 Conduct weather routing



In this process the weather data, which has been gathered by the UAS itself, is evaluated. It is compared with weather forecasts that have been received from shore via the SCC. Considering both types of weather data a valid estimation of current and upcoming weather conditions along the planned track of the UAS can be made. Combined with certain predefined parameters and taking into account stability and maneuverability conditions a route optimization is conducted under weather routing criteria.

Input parameters are weather data on the one hand and ship data on the other hand. The weather data comprises data measured by the UAS as well as forecast data provided by weather stations ashore. The data includes strength and direction of wind, wind waves, swell and current in the area within the ship’s range during the forecast period. Moreover ship data is considered. This comprises not only routing parameters based on ECDIS data but also data regarding the hull form, the propulsion system and coming along with this stability, seakeeping and maneuvering parameters.

Based on a weather analysis and a ship response optimization the output of this process is a route waypoint optimization. In the weather analysis especially strength and direction of wind, wind waves, swell and current in the area within the ship’s range are elaborated during the forecast period. Utilizing the results of the weather analysis the next step aims to monitor and then predict the seakeeping and maneuvering behavior of the UAS to optimize the ship’s responses. This is of interest as unfavorable wind loads, wave lengths, wave heights or angles of encounter can cause large roll angles and accelerations, slamming, loss of stability, shift of cargo or even capsizing. Thus, these unfavorable weather conditions need to be avoided by a route waypoints optimization based on weather analysis and ship response optimization.

The process output is a recommendation regarding optimized route waypoints under consideration of current and forecast weather conditions as well as the characteristics of the UAS. Notification on the routing and its optimization possibilities are provided in order to allow an adjustment of the track. The automated optimization of route waypoints can help to increase fuel efficiency and to ensure a safe and smooth voyage.

5.5 Provide engine data

Relevant data from the EAS is being forwarded to the appropriate bridge processes. Within work package 6 of the MUNIN project further details are being elaborated.

As mentioned in chapter 5.1 the speed of the ship is one of its key values for navigating and maneuvering. Other important values for these tasks are for example the rudder angle, engine load and fuel consumption. All these values have in common that they are related to parts of the engine room. The bridge is responsible for navigation and requires this key data from the engine room while it also has to target these values for the engine room.

The engine room data is basically split into two parts. The first part refers to the data sent from the bridge to the engine room. These data are in general control commands and target values. The control commands are used to start and stop components like the main engine, auxiliary engines or processes such as ballasting or bunkering of fuel or water. The targeted values are for example the propeller speed or the rudder angle. The commands will be handled by the Autonomous Engine Monitoring and Control system AEMC and then forwarded to the EAS. The other part of the data is related to the measured values needed for bridge calculation and status reports. These sensor readings of temperatures, pressures and filling levels will be directly delivered to the automation system and the engine room controller will process the received values from the EAS for the bridge. For general data sharing between bridge and engine room an interface is required which will be described in chapter 7.2 of this document.

As an output for this connection between the bridge and the engine room the ABS has the ability to navigate the ship and control the needed parts of the engine room systems. In addition to this the ABS receives information about the condition of key engine room values and has the possibility to react on upcoming situations early.

5.6 Determine ship status

The ship status process collects information which are needed to continuously establish a thorough motion model of the ship and its operational condition.

The current displacement, trim, heel, draft in forward, midship and aft position, translatory ship motions such as surge, sway and heave as well as rotatory ship motions such as roll, pitch and yaw are gathered from respective sensors. In addition, main engine, steering gear and thrusters submit their status data to this process. For the purpose of buoyancy and stability control data about hull stresses and hull integrity are

also gathered. Furthermore, to calculate weight distribution ullages of ballast and fuel tanks are collected within this process while data concerning cargo monitoring will have to be submitted by the SCC to a certain extent.
The main objective of this process lies in gathering, evaluating and distributing the available status sensor data. This is necessary to continuously assess the current situation of the ship under the prevailing conditions and to predict its behavior under possible future conditions.
The data distributed is a set of information containing a detailed model of the ship's movements along with the status of propulsion, steering, hull and cargo. This will be used to determine the ship dynamics and to control its buoyancy and stability.

5.7 Determine ship dynamics

Within this process the basis for planning maneuvers is to be laid out. It is based on a ship's model which must be assessed continuously on its accuracy. Therefore the actual ship dynamics must be identified as exactly as possible.
The information can be taken from the ship's own sensor system whereas the position data and speed components form the most important information for this process. For the assessment of the ship's model measurements during time laps of relevant length are required in order to obtain resilient time series of these data.
This dynamic data can be grouped into the different sets of information. The general parameters consist of position, longitudinal and transversal speed over ground and through water, RoT, course, heading, roll and pitch angle, wind direction and force, current direction and force, water depth, engine mode and system time. The rudder parameters indicate the commanded and the actual rudder angle, the rudder pump mode and possible other parameters for specific rudder types, if required. In a similar way, the commanded and the actual value for any thruster on board are indicated along with other parameters for specific thruster types. Propulsion parameters consist of the EOT, commanded and actual RpM or pitch, respectively as well as possible other parameters for specific propulsion plants.
The main objective of this process lies in the evaluation and redefinition of the ship's model in order to be able to properly assess the situation in the maneuver planning process.
The output will be the identification of the exact actual ship dynamics which are required to determine the ship's maneuverability. This only enables realistic planning for the execution of weather routing and collision avoidance. The following three information sets should at all times be available and continuously be adapted to the current situation to ensure fast reaction in case of emergency:

- Prediction of turning circles to port and starboard until a deviation of 90° from the original heading is reached

- Prediction of crash stop distance
- Other required maneuvers to ensure a defined ship's domain

The presentable output parameters for these various predicted maneuvers are the same as the above mentioned input parameters, but calculated for the future ship's movement.

5.8 Control autonomous ship

The SCC bridge control plays a central role within the operation of the UAS. The current situation of the UAS is constantly monitored based upon the data received via the ship's log book or via the receipt of a direct notification. At all times the SCC has full access to UAS data, can set parameters and enter relevant information.

From a separate SCC process, a complete voyage plan document is received for review and approval. But to the largest extent, input data originates from the UAS and mostly from the log book process. Standard information about the progress of the voyage, such as courses steered, distances sailed, positions fixed, embarkations and disembarkation as well as other notable events are submitted within a standard routine interval. In case of incidents occurring, separate notifications are received to provide information concerning weather routing, collision avoidance or emergency situations. These incident notifications might include a request for assistance in solving a specific situation. In addition to that, all voice radio communication is relayed to the human SCC operator.

This process serves as the central point for information exchange between ship and shore. The data passing through is viewed by an operator to allow an assessment of the current situation on board. Based on this assessment and further criteria, the SCC might take corrective action and intervene with autonomous ship operation.

The control of the UAS is conducted either by the adjustment of parameters for e.g. the ship's routing or by the provision of information updates concerning voyage planning, nautical publications and weather forecasts.

5.9 Follow track (autopilot)

The track laid out by the voyage plan and any adjustments thereto made by weather routing or collision avoidance measures are being carried out by the automatic track pilot within the SCC-set steering parameters.

Steering parameters must be pre-set manually and contain thresholds for radius and rate of turn for course changes at waypoints. Modern track pilots don't just control the ship's steering but also its speed by either a set allowance or a set time of arrival at a certain position. Sensor input on the other hand comprises the ship's position, speed through water and over ground, heading, RoT and the rudder angle indicator value.

By comparison of the actual with the desired position value the track pilot calculates the cross track distance, which is the deviation from the planned track. An algorithm is then used to determine and compensate for any disturbance values, accounting for all above mentioned sensor input values.

A desired rudder angle value is produced as output data and executed by the steering gear. Track control systems must be capable to keep as close as 50 meters to the aspired track while the most modern systems barely produce an XTE of more than 10 to 20 meters.

System	Obligation	Trigger	Process word	Object	Legal Regulations
The ABS	must	be capable to	receive	position, heading, rate of turn and speed of own ship (relevant for identification of deviation from course line)	MSC. 64(67) Annex 3
The ABS	must	be capable to	receive	own ships voyage plan (needed to identify planned actions e.g. change of course at waypoint and scheduled position and heading)	SOLAS Chapter V R34, IMO Resolution A.893(21)
The ABS	must	be capable to	receive	information on the environmental conditions (in heavy sea deviations from scheduled course may not induce action as early)	SOLAS Chapter V R34, IMO Resolution A.893(21)
The ABS	must	be capable to	consider	ships maneuvering characteristics	IMO Resolution A.601(15) MSC.137(76)
The ABS	must		evaluate	own ship's true position and speed in comparison with the voyage plan	
The ABS	must		identify	deviation between planned and actual situation taking into account current environmental conditions	SOLAS Chapter V R34, IMO Resolution A.893(21)
The ABS	must		evaluate	when deviation becomes unacceptable	STCW A-VIII/2 Part 2 (7)
The ABS	must		evaluate	if deviation can be made up for (small deviation)	STCW A-VIII/2 Part 2 (7)
The ABS	must		initiate	action to return to planned situation / maneuvering status (if deviation is only small and can be made up for)	---
The ABS	must		notify	the SCC (if deviation from planned track gets significant)	---
The ABS	must		initiate	actions scheduled in the voyage plan (e.g. change of course at waypoint)	SOLAS Chapter V R34, IMO Resolution A.893(21)
The ABS	must	offer SCC the possibility to	define	parameters and thresholds relevant for following the planned track (e.g. what degree of deviation shall initiate an action)	---
The ABS	must	be capable to	receive	orders (to steer and maneuver)	STCW Table A-II/4
The ABS	must		perform	steering and steer and maneuver actions	STCW B-II/1 (11.4)
The ABS	must		identify	if steering actions are carried out properly by the maneuvering equipment	MSC.74(69) MSC.252(83)
The ABS	must		notify	the SCC (if there is a problem with the steering gear)	---
The ABS	must	offer SCC the possibility to	control	steering and sailing actions	---
The ABS	must/shall	…	…	…	…

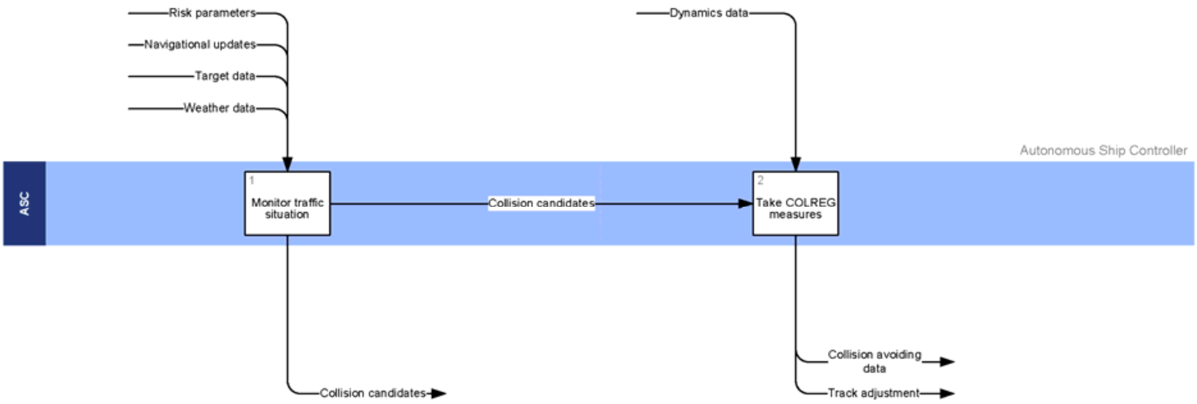
5.10 Control buoyancy and stability

This process relies on the information about the prevailing situation which is provided by the ship status process. Thereupon this process arranges adequate measures in order to achieve a satisfactory buoyancy and stability.

The required information from the ship status process are the distribution of masses from ballast and fuel tanks and cargo as well as the ship's trim, heel and draft in forward, midship and aft position. Data about the ship's motion within its 6 degrees of freedom is required as well.

This process must carry out a calculation upon above mentioned information to assess the current floating condition and, if thresholds are exceeded, to take adequate measures in collaboration with other ship tools for e.g. ballast or bunker activities.
If situation demands, measures to ensure sufficient buoyancy and stability are carried out. In any case a status flag will indicate the current situation and possible actions to the SCC.

5.11 Avoid collision



To navigate the UAS safely and COLREG-compliant it is necessary to continuously monitor the current traffic situation. To do so, all traffic-related data is combined and assessed within this subprocess of collision avoidance. Possible future developments are being predicted and as soon as a potential close quarters situation is identified, appropriate COLREG measures are being taken.
To properly define the current traffic situation it is essential to ascertain the ship's position on an electronic navigational chart with full information accessibility. In order to predict the own ship's movement, the full set of location and dynamics data is required as well. Additionally, the various data sets from both lookout processes are needed. At all times the SCC has an overruling function in order to be able to adjust data settings e.g. risk parameters for ship domain or safety contour or to order specific evasive maneuvers.
This input data is then combined to establish a vision of the vicinity of the ship. All identified objects, e.g traffic ships, aids to navigation, floating debris or PiWs are diligently monitored. The intended routes of traffic target ships are predicted, evaluated and possible upcoming close quarters situations are identified. In case such a situation occurs it is clarified which ship is obliged to perform what action under the COLREG regime, applying the proper set of rules for the prevailing visibility conditions. Once the own ship's obligations have been identified possible solutions to this situation are elaborated and assessed. Multiple solutions are calculated, taking into account possible maneuvers of the collision candidate and avoiding close quarters situations with other ships in the vicinity. The traffic situation needs to be continuously monitored and

assessed to be able to adopt to maneuvers of traffic ships. Should no suitable measure be identified to avoid a pending collision, assistance from the SCC will be requested.

An appropriate response to a specific traffic situation is identified, either maintaining steady course and speed or taking early and substantial action to keep well clear. This comprises specific measures in the form of orders for rudder angle and engine telegraph. In case a traffic ship does not comply with COLREGs or behaves in an unusual manner, posing a threat to safety, a message may be transmitted, inquiring its intentions. In such an event, the SCC will be notified as well. Also, all information about maneuvers carried out by any ship involved must be shared with the SCC. If a demanding traffic situation should develop the output data is forwarded at a higher rate. It is also reported to the SCC if the close quarters situation has been resolved and the ships have passed well clear of each other.

5.12 Plan voyage

The voyage planning process is being performed to identify the most favorable route under routing criteria. The preparation of a thorough plan from berth to berth covers ocean passages, coastal voyages and pilotage waters. It is produced ashore by the SCC and then forwarded to the UAS.

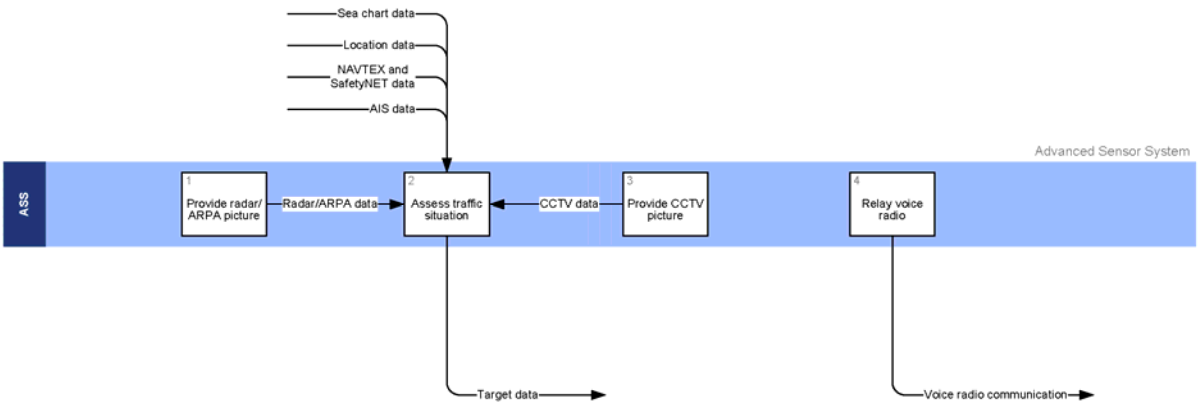
Firstly, the specific ship's characteristics need to be respected as for its stability, draft, trim, equipment, maneuverability and any operational limitations. Also, the nature of the loaded cargo and its weight distribution and safe stowage need to be accounted for. Secondly, a complete and up-to-date documentation of certificates, nautical publications and sea charts is required. Thirdly, current information such as existing radio navigational warnings and weather reports for the relevant sea areas need to be viewed. Fourthly, departure and arrival requirements for the respective ports are to be considered as well as ship routing and reporting measures within the transited sea areas. Fifthly, the ship's provisions of fuel, lubricants and other supplies have to be verified.

On the basis of above information, a detailed voyage plan is prepared by the SCC which covers the entire voyage. This plan should lay out the voyage track and contain a list of waypoints, true courses of each leg, leg distances, wheel-over positions and turn radius for course alterations and maximum allowable off-track margins. Additionally such attributes as information about routing and reporting systems and areas which require special considerations in respect to safety, security and environmental protection should be included. These elements comprise e.g. safe speed and potential speed alterations, permissible UKC, machinery status requirements, fuel bunker and range as well as frequency and methods of position fixing. Furthermore, voyage planning aims for efficient ship operation and therefore the most favorable permissible route to save time and fuel should be chosen. Especially for ocean transits the prevailing currents and

winds have to be accounted for in this respect and the compliance with the LLC has to be ascertained.
As a voyage plan, a clear record should be produced, with all necessary information marked on the navigable sea charts and written in a document format accessible for humans and ABS alike. This record is than transmitted to the UAS and counterchecked before implementation.

System	Obligation	Trigger	Process word	Object	Legal Regulations
The ABS	must		consider	changes / adjustments to the voyage plan during the voyage	STCW A-VIII/2 Part 4 (7)
The ABS	must		ascertain	voyage plan is in compliance with COLREGs	COLREG
The ABS	must		consider	corrections of nautical publications and sea charts that affect the current voyage plan properly	SOLAS Chapter V R19 2.1.4
The ABS	must		evaluate	if the voyage plan is legitimate / valid / feasible	STCW B-II/1 (11.1.9)
The ABS	must		provide	new voyage plan to other ABS processes	---
The ABS	must/shall	...	...	...	...

5.13 Conduct lookout (traffic)



Within this process data from navigational and safety sensors is collected and assessed to build a local map of ships, objects and other navigational hazards. The approach fuses and correlates data from multiple sensors to reduce overall uncertainty and improve the quality and integrity of the map. This complete traffic picture will be used to initiate actions or to notify the SCC. Voice radio communication is also handled within this process and relayed to the SCC.
To enable a thorough lookout, own ship's data such as position, heading, speed and UKC is needed in the first place. Then, navigational sensors on board the UAS constantly gather data to generate a complete traffic picture of the vicinity of the ship. To do so, targets are detected, identified and tracked. This traffic assessment is supported by the CCTV picture. The process receives input from own vessel sensors and other ABS and SCC modules. The main vessel sensors are the radar, for raw readings and ARPA information, AIS for reported vessel locations and other safety information, NAVTEX for

navigational and meteorological warnings, and infrared and daylight images for automated processing and detection of unknown hazards. In addition, the process will use a-priori navigational chart data alongside weather, tide, depth and visibility information to detect potential navigational hazards ahead of time.

The main objective is to collect, process, verify and output observation of the current and future navigational and vessel traffic environment around the own ship. Sensor data is collected at different rates and with various degree of accuracy. This process will fuse the observations by correlating related observations from different sensors. This will eliminate wild points and statistical noise from the readings and provide a robust representation of the current and future traffic situation surrounding the ship.

The output will be a set of target data and features in the vicinity of the vessel with potential threats highlighted. The sensor fusion process also will annotate each target with a confidence level based on the correlations between different sensor types. This process provides both a local map of the environment and warnings about potential hazards based on the own ship current and predicted status and position as well as those of the objects detected.

5.14 Receive NAVTEX and SafetyNET data

Maritime safety information which is being distributed through the NAVTEX and SafetyNET service is received by the UAS and forwarded to the appropriate processes. As the transmission's composition is not fully standardized it might be difficult to interpret them automatically.

These messages may consist of navigational and meteorological warnings, meteorological forecasts, SAR and other urgent information.

The information received is being interpreted and distributed to its respective lookout process for further use.

The NAVTEX and SafetyNET data which is being distributed either to the lookout (weather) or lookout (traffic) process will contribute to establish a thorough perception of the surrounding of the ship.

5.15 Manage alarms and emergencies

All potential emergency situations are being managed within this process and are intended to draw attention to abnormal situations and conditions.

In case a permissible threshold is exceeded in any part of the ship, an alert message will be received by this process. There is a large quantity of possible indications for malfunctions or abnormal conditions of machinery parts such as main engine, auxiliary engines, bilges, steering gear or electrical installations. Other alert messages can be related to either navigation, cargo or personnel, e.g. engineers alarm or bridge navigational watch alarm. Distress alerts will be raised in case a respective message is received or if an indication of distress has been detected. An emergency such as fire or leakage is indicated by a fire detection alarm and local fire-extinguishing system activation alarm or a water ingress detection alarm and power-operated watertight door fault alarm, respectively. Beyond that, an alert message notifies in case of faults of control systems. This list of alarm inputs continues with further additional alarms for specific ship types such as gas detection alarm on tankers for example.

The main purpose of this process is to concentrate all ship alert messages within one system to provide the SCC with a single point of access for the management of alarms and emergencies.

From this centralized management system the alert messages will be forwarded to the SCC and indicate a status change of the ship. Depending on the severity of the alarms and the possible or expected consequences of the prevailing situation, further alarms will be raised on board, e.g. general emergency, fire, abandon ship or ship security alarm. These alarms may be accompanied by the emission of distress, urgency or safety messages via the GMDSS network. Furthermore, specific countermeasures can be taken automatically by the UAS to cope with the prevailing situation. These measures may comprise a change of the ship's operational mode and the determination and execution of appropriate Fail-to-Safe FtS or SAR procedures.

5.16 Receive AIS data

Data relevant to promote the safety of navigation by facilitating tracking, identifying and locating is received from other AIS transceivers in the vicinity.

Depending on the emitting ship's speed the different AIS messages are broadcasted every 2 to 10 seconds, every 3 minutes or every 6 minutes. This messages consist of static ship's data such as its IMO- and MMSI-number, name, type, call sign and dimensions. Dynamic ship's data such as navigational status, position with time, course and speed over ground, heading and RoT is also transmitted. Additionally voyage data like current draft, hazardous cargo, port of call, estimated time of arrival and the number of crew on board are to be broadcasted.

The input data of up to 500 ships is gathered and updated individually within the transceiver. In case this number should be exceeded, those targets with the greatest distance from the own ship will be rejected by the system. Thus a complete overview of AIS targets within a range from 20 nm to 30 nm is established. In sea areas in which AIS repeater stations are fitted, this range can be enlarged beyond that.

This traffic overview is forwarded to the conduct lookout (traffic) process to be fused together with other input data to form an even more thorough and more complete overview of the traffic in the vicinity of the vessel.

6. Specification requirements for the Autonomous Bridge System

6.1 Determine position, heading, speed and depth

In this process data from various ship's sensors is gathered and evaluated in order to thoroughly determine the position and heading of the ship. Redundant sensors and positioning by multiple sources ensure a high degree of data accuracy. The current speed and water depth is determined as well. The legal foundation for these requirements can mainly be found within SOLAS, STCW, COLREG and several IMO resolutions.

System	Obligation	Trigger	Process word	Object	Legal regulations
The ABS	must	be capable to	receive	data from own ship sensors (compass)	SOLAS Chapter V R19 2.1.1 MSC.252(83)
The ABS	must		determine	compass error	SOLAS Chapter V R19 2.1.3 STCW B-II/1 (11.1.5)
The ABS	must		perform	correction of compass error (if compass error is identified)	SOLAS Chapter V R19 2.1.3 STCW B-II/1 (11.1.5 & 11.1.8) STCW A-VIII/2 Part 4-1 (34.2)
The ABS	must	be capable to	receive	data from own ship sensors (speed log data)	SOLAS Chapter V R19 2.3.4 MSC.252(83)
The ABS	must	be capable to	receive	data from own ship sensors (radio navigation data)	SOLAS Chapter V R19 2.1.6 MSC.252(83)
The ABS	must	be capable to	receive	data from own ship sensors (radar/ARPA navigation data)	COLREG R5/R6/R7/R19 SOLAS Chapter V R19 2.3.2/2.3.3/2.7 MSC.64(67) Annex 4 MSC.252(83) STCW B-II/1 (11.3)
The ABS	must	be capable to	receive	data from own ship sensors (GNSS)	SOLAS Chapter V R19 2.1.6 MSC.252(83)
The ABS	must	be capable to	receive	data from own ship sensors (automatic sextant: position of celestial bodies)	STCW B-II/1 (11.1.7)
The ABS	must		evaluate	data from own ship sensors (to determine position and heading)	STCW B-II/1 (11.2) MSC.252(83)
The ABS	must		calculate	own ships position and heading by more than one method (including terrestrial, celestial and technical navigation techniques)	STCW Table A-II/1
The ABS	must		evaluate	own ships position depending on different methods of positioning	STCW Table A-II/1
The ABS	must		identify	deviations of own ships position calculated by different methods	STCW Table A-II/1
The ABS	must		notify	the SCC (if ambiguity of own ship's position is found)	---
The ABS	must		calculate	own ships movements based on data from own ship sensors (speed, acceleration, heading, roll, pitch, yaw, surge, sway, heave)	STCW A-VIII/2 Part 4-1 (25)
The ABS	must		provide	information on own ships position, heading and movement to other ABS processes	SOLAS Chapter V R28 (2)
The ABS	must	offer SCC the possibility to	access	information on position and heading of own ship	SOLAS Chapter V R28 (2)
The ABS	must	be capable to	receive	data from own ship sensors (echo sounder)	SOLAS Chapter V R19 2.3.1

System	Obligation	Trigger	Process word	Object	Legal regulations
The ABS	must		calculate	current under-keel clearance (Obs tide differences)	STCW A-VIII/2 Part 5-3 (102.2.2)
The ABS	must		detect	insufficient under-keel clearance (Need to be predictive)	STCW A-VIII/2 Part 5-3 (102.2.2)
The ABS	shall		monitor	all sensors	STCW A-VIII/2 Part 4-1 (17.9 & 18.7)
The ABS	shall		determine	an appropriate response (if a sensor failure should be encountered)	STCW Tabel A-VII/1 & A-VII/2
The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
The ABS	must/shall	…	…	…	…

6.2 Conduct lookout (weather)

In this process, the UAS independently gathers weather data from its own sensors. It is its purpose to establish a thorough perception of the current environmental surrounding of the ship. The accumulated data is used for subsequent weather routing and is also stored and provided to the SCC. The legal foundation for these requirements can mainly be found within COLREGs, SOLAS, STCW and several IMO resolutions.

Subprocess	System	Obligation	Trigger	Process word	Object	Legal regulations
Measure weather data	The ABS	must	be capable to	receive	data from own ship meteorological sensors	STCW Table A-II/1 and Table A-II/2
Measure weather data	The ABS	must	be capable to	consider	Radar/ARPA information (to identify current sea state)	COLREG R6 a)v SOLAS Chapter V R19 2.3.2/2.3.3/2.7
Measure weather data	The ABS	must		identify	current sea state information	STCW A-VIII/2 Part 4-1 (16.2 & 17.1)
Measure weather data	The ABS	must		detect	areas of limited visibility	COLREG R19
Provide CCTV picture	The ABS	must	be capable to	consider	CCTV information (to capture current environmental condition, e.g. visibility, cloud picture and movement, sea state)	---
Assess weather data	The ABS	must		evaluate	information about the environment from all available sources to define the current environmental condition	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess weather data	The ABS	must	be capable to	consider	own ship meteorological observation system information (e.g. air and water temperature, atmospheric humidity, atmospheric pressure, wind characteristics)	SOLAS Chapter V R5 2.4
Assess weather data	The ABS	must		provide	meteorological information to other ABS processes	SOLAS Chapter V R5 2.5
Assess weather data	The ABS	must	offer SCC the possibility to	access	information on possible upcoming and current threats	SOLAS Chapter V R34 (2), IMO Resolution A.893(21)
Assess weather data	The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
…	The ABS	must/shall	…	…	…	…

6.3 Conduct weather routing

In this process, the weather data which has been gathered by the UAS itself is evaluated in comparison with weather forecasts which have been received from shore via the SCC. With this data combination a valid estimation of current and upcoming weather conditions along the planned track of the UAS can be made. Combined with certain predefined parameters and taking into account stability and maneuverability conditions a route optimization is conducted under weather routing criteria. The legal foundation for these requirements can mainly be found within SOLAS, STCW, IS-code and several IMO resolutions.

Subprocess	System	Obligation	Trigger	Process word	Object	Legal regulations
Evaluate weather data	The ABS	must	be capable to	receive	meteorological forecasts (mainly information about wind, sea state and current)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	must	be capable to	receive	own ship's meteorological observation data	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	shall		evaluate	external meteorological information in comparison with own meteorological observation data	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	shall		evaluate	external meteorological information by comparison with own meteorological observation data to improve forecast of upcoming environmental conditions	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	shall		notify	the SCC (if discrepancy between expected and current weather exceed a predefined threshold)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	must		monitor	current environmental conditions (sea state, wind, etc.)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	must	be capable to	consider	own ships current course / own ships voyage plan	SOLAS Chapter V R34, IMO Resolution A.893(21) STCW A-VIII/2 Part 4-1 (34.1)
Evaluate weather data	The ABS	must	be capable to	consider	meteorological forecasts relevant for planned voyage	SOLAS Chapter V R34, IMO Resolution A.893(21)
Evaluate weather data	The ABS	must		evaluate	upcoming environmental conditions along ships route (relying on weather forecasts)	SOLAS Chapter V R34 (2.3) IMO Resolution A.893(21)
Assess route optimization	The ABS	must	offer SCC the possibility to	define	weather routing parameters	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	must	offer SCC the possibility to	define	the threshold where environmental conditions pose a threat to the ship by taking into account the ships maneuvering characteristics	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	must		identify	possible threats due to current environmental conditions	SOLAS Chapter V R34, IMO Resolution A.893(21) STCW A-VIII/2 Part 4 (12)

Subprocess	System	Obligation	Trigger	Process word	Object	Legal regulations
Assess route optimization	The ABS	must		identify	possible threats due to upcoming (predicted) environmental conditions	SOLAS Chapter V R34 (2.3) IMO Resolution A.893(21) STCW A-VIII/2 Part 2 (7)
Assess route optimization	The ABS	must		initiate	actions (if threats along the planned route of own ship related to upcoming environmental conditions are identified)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	must		initiate	actions (if threats related to current environmental conditions are identified)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	shall	offer SCC the possibility to	define	routing parameters / restrictions (time of arrival fix or time frame, minimize cost etc.)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	shall	be capable to	consider	own ship's stability properties (to take them into account when calculating optimal route in the expected environmental circumstances)	SOLAS Chapter V R34, IMO Resolution A.893(21) IS Code Res.A.749 (18) MSC/Circ.920
Assess route optimization	The ABS	shall	be capable to	consider	own ship's maneuvering properties (to take them into account when calculating optimal route in the expected environmental circumstances)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	shall	be capable to	access	current voyage plan	SOLAS Chapter V R34, IMO Resolution A.893(21) STCW A-VIII/2 Part 2 (6)
Assess route optimization	The ABS	shall		evaluate	alternative routes under routing restrictions	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	shall		determine	whether alternative routes are favorable enough to justify a route change	SOLAS Chapter V R34, IMO Resolution A.893(21) STCW A-VIII/2 Part 2 (7)
Assess route optimization	The ABS	shall		perform	an adjustment of the route (if alternative route is found favorable)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	shall		notify	the SCC (if an alternative route is found favorable and route is adjusted)	SOLAS Chapter V R34, IMO Resolution A.893(21)
Assess route optimization	The ABS	must	be capable to	evaluate	the consequences that deviations from the planned track might have on the further voyage	SOLAS Chapter V R34, IMO Resolution A.893(21) STCW A-VIII/2 Part 2 (7)
Assess route optimization	The ABS	must		provide	information on weather routing recommendation to other ABS processes	SOLAS Chapter V R34, IMO Resolution A.893(21) IS Code Res.A.749 (18) MSC/Circ.920
Assess route optimization	The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
…	The ABS	must/shall	…	…	…	…

6.4 Determine ship status

For the appropriate determination of the status of the ship, the required data is gathered within this process. Some data such as position, heading, speed and depth as well as weather data is generated within processes of their own. That's why ship status data only comprises displacement, draft, trim, ship motions within 6 degrees of freedom and information about propulsion and steering systems. Cargo monitoring is also part of the ship status process. The legal foundation for these requirements can mainly be found within SOLAS, STCW, CSS-code, IS-code, several IMO resolutions and circulars as well as in e.g. national German legislation.

System	Obligation	Trigger	Process word	Object	Legal Regulations
The ABS	must		calculate	specific ships variable characteristics (e.g. displacement, draft, trim, ship's movement)	IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must	be capable to	receive	technical data from other ship systems (current status of e.g. the engine, ballast system, fuel)	SOLAS Chapter II-1 Part C R51 STCW A-VIII/2 Part 4-1 (17.9 & 18.7)
The ABS	must	offer SCC the possibility to	transmit	cargo-related data to the ship	HGB §535 (2) (German law)
The ABS	must		monitor	cargo spaces to identify shift of cargo and further dangers such as fire, ect.	IMO Resolution A.714(17) SOLAS Chapter II-2 Part C R7
The ABS	must	be capable to	ascertain	the save loading, lashing and care of cargo during the voyage	IMO Resolution A.714(17) CSS Code Annex 13
The ABS	must	be capable to	control	the cargo hold meteorology	HGB §535 (1) & HGB §606 (German law)
The ABS	must	be capable to	detect	defects and damages to cargo and ship's hull	STCW Table A-II/1
The ABS	must/shall	...	...	...	...

6.5 Determine ship dynamics

In order to safely navigate the dynamics of the ship have to be determined continuously. Own ship's characteristics have to be accounted for as well as environmental conditions. The legal foundation for these requirements can mainly be found within SOLAS, STCW, COLREGs, IS-code and several IMO resolutions.

System	Obligation	Trigger	Process word	Object	Legal regulations
The ABS	must	be capable to	receive	current sea charts (to be able to identify impact of shallow or narrow waters on maneuvering properties)	STCW A-VIII/2 Part 2 (5)
The ABS	must	be capable to	receive	current water depth from echo sounder (to be able to identify impact of shallow or narrow waters on maneuvering properties)	SOLAS Chapter V R19 2.3.1
The ABS	must	be capable to	receive	information on environmental conditions	STCW A-VIII/2 Part 4-1 (16.2)
The ABS	must	be capable to	receive	further navigational data (course over ground, heading, position, speed, under-keel clearance)	IMO Resolution A.601(15) MSC.137(76)
The ABS	must	be capable to	receive	current stability conditions	IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must		initiate	a calibration by performing likely maneuvers	IMO Resolution A.601(15) MSC.137(76)
The ABS	shall		learn	from maneuvers previously carried out to improve its calibration	IMO Resolution A.601(15) MSC.137(76)
The ABS	must		consider	the effects of wind, sea state and current on own ships maneuvering properties	IMO Resolution A.601(15) MSC.137(76)
The ABS	must		consider	the effects of shallow or narrow waters	STCW Table A-II/2
The ABS	must		consider	possible restrictions on own ships maneuvering abilities (if e.g. engine availability is restricted)	COLREG R6 a)iii
The ABS	must		consider	specific constant ship characteristics (e.g. dimensions)	IMO Resolution A.601(15) MSC.137(76)

System	Obligation	Trigger	Process word	Object	Legal regulations
The ABS	must		determine	constantly the ships maneuvering characteristics	IMO Resolution A.601(15) MSC.137(76)
The ABS	must		determine	own ships maneuvering characteristics under different conditions (e.g. speed, sea state, water depth)	IMO Resolution A.601(15) MSC.137(76)
The ABS	must		provide	own ships maneuvering characteristics to other ABS processes	IMO Resolution A.601(15) MSC.137(76)
The ABS	must	offer SCC the possibility to	access	own ships current maneuvering characteristics	IMO Resolution A.601(15) MSC.137(76)
The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
The ABS	must/shall	…	…	…	…

6.6 Control buoyancy and stability

Within this process, the weight distribution on board the UAS is calculated to determine and control the ship's buoyancy and stability. The required data is either generated by shipboard sensors or received from the SCC. To balance uneven weight distribution and to ensure sufficient stability ballast operations are carried out. The legal foundation for these requirements can mainly be found within CSS-code, IS-code, BWM-regulation as well as within several IMO resolutions and circulars.

System	Obligation	Trigger	Process word	Object	Legal Regulations
The ABS	must	be capable to	control	actual drafts, trim, heel, stability and stress of the vessel (calculation of stability relevant parameters (e.g. GM) and comparison to their thresholds)	IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must		calculate	constantly the ships stability and displacement status	IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must		provide	stability information to other ABS processes	IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must	be capable to	initiate	countermeasures to dangerous changes in cargo and stability condition	IMO Resolution A.714(17) Chapter 7 IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must		notify	the SCC (if the ships stability and displacement status can't be calculated)	---
The ABS	must		notify	the SCC (if the maneuvering characteristics can't be determined)	---
The ABS	must	be capable to	notify	the SCC (if defects and damages to cargo and ship's hull have been detected)	---
The ABS	must		notify	the SCC (if the maneuvering characteristics can't be forwarded to other ABS processes)	---
The ABS	must		notify	the SCC (if the current stability of the ship changes considerably without a change in ballast)	---

System	Obligation	Trigger	Process word	Object	Legal Regulations
The ABS	must		notify	the SCC (if an increasing displacement indicates a water inrush)	---
The ABS	must		notify	the SCC (if the current stability of the ship reaches stability limits)	---
The ABS	must		receive	necessary data to calculate stability (loading and ballast condition, draft, trim, heel, …)	IS Code Res.A.749 (18) MSC/Circ.920
The ABS	must	be capable to	control	the ballast water management (if cargo condition changes, e.g. due to changing cargo hold meteorology, fuel consumption or damage to ship's hull)	BWM Regulation A until E
The ABS	must	be capable to	ascertain	compliance with ballast water requirements	BWM Regulation A until E
The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
The ABS	must/shall	…	…	…	…

6.7 Avoid collision

To navigate the UAS safely and COLREG-compliant it is necessary to continuously monitor the current traffic situation. To do so, all traffic-related data is combined and assessed within this process and possible future developments are being predicted. As soon as a potential close quarters situation is identified, appropriate measures are being taken. The legal foundation for these requirements can mainly be found within COLREGs but also in SOLAS, STCW, IS-code, bridge procedure guides as well as several IMO resolutions and circulars.

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
Monitor traffic situation	The ABS	must	offer SCC the possibility to	define	parameters	---
Monitor traffic situation	The ABS	must	be capable to	access	information about the surrounding area via the ENC	MSC.252(83)
Monitor traffic situation	The ABS	must	be capable to	receive	own ship's meteorological data	STCW A-VIII/2 Part 4-1 (16.2)
Monitor traffic situation	The ABS	must	be capable to	receive	own ship's traffic target data	STCW A-VIII/2 Part 4-1 (16.2)
Monitor traffic situation	The ABS	must		monitor	objects in vicinity (e.g. ships, aids to navigation, floating debris, PIWs)	STCW A-VIII/2 Part 4-1 (16.2)
Monitor traffic situation	The ABS	shall		identify	abnormal activity by ships in vicinity (e.g., gaining on own ship, not following COLREGs)	COLREG R17 a)ii, R2
Monitor traffic situation	The ABS	must		evaluate	upcoming development of traffic situation	SOLAS Chapter V R34, IMO Resolution A.893(21)
Monitor traffic situation	The ABS	shall		evaluate	intended routes of other ships based on AIS and ENC information available	SOLAS Chapter V R19 2.4
Monitor traffic situation	The ABS	can		evaluate	intended routes of other ships based on visual and radar information	COLREG R5/R6 b)v

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
Monitor traffic situation	The ABS	must	offer SCC the possibility to	define	parameters relevant to avoid close quarters situations	---
Monitor traffic situation	The ABS	must		identify	possible upcoming close quarters situations	COLREG R5
Monitor traffic situation	The ABS	must		notify	the SCC (if a close quarters situation is developing)	---
Monitor traffic situation	The ABS	must	offer SCC the possibility to	access	information about upcoming close quarters situations and proposed safe deviation routes	COLREG R8
Monitor traffic situation	The ABS	shall	offer OBP the possibility to	access	information about the upcoming close quarters situation	COLREG R7
Monitor traffic situation	The ABS	must		provide	information about the current traffic situation to other ABS processes	COLREG R6 a)ii
Take COLREG measures	The ABS	must	be capable to	receive	own ship's stability data	IS Code Res.A.749 (18) MSC/Circ.920
Take COLREG measures	The ABS	must	be capable to	receive	own ship's maneuverability data	COLREG R6 a)iii
Take COLREG measures	The ABS	must		transmit	the traffic picture to the SCC	COLREG R5/R6 b)v
Take COLREG measures	The ABS	shall		transmit	parameters at higher update rates to SCC (if collision avoidance activities are performed)	---
Take COLREG measures	The ABS	must		consider	COLREGs while navigating	COLREG R1 a
Take COLREG measures	The ABS	must	be capable to	evaluate	which collision avoidance rules apply under the prevailing visibility conditions	COLREG R7
Take COLREG measures	The ABS	must		identify	if own ship is give-way ship or stand-on ship	COLREG R16/17
Take COLREG measures	The ABS	must		ascertain	possible solutions to avoid upcoming close quarters situations in compliance with COLREGs (if a danger of collision is identified)	COLREG
Take COLREG measures	The ABS	shall		calculate	a relative waypoint to pass the stand-on ship clear astern (if own ship is not the stand-on ship)	COLREG R15
Take COLREG measures	The ABS	must		provide	solutions for upcoming collision situations to other ABS processes (if a danger of collision is identified)	COLREG R9/10/13/14/15/19
Take COLREG measures	The ABS	shall		notify	the SCC (if abnormal activity by other ships is identified that might pose a threat)	(BPG 1.3.1)
Take COLREG measures	The ABS	must		notify	the SCC (if an appropriate collision avoidance maneuver has been identified)	(BPG 1.3.1)
Take COLREG measures	The ABS	must		notify	the SCC (if the system requires assistance in finding a valid solution to avoid pending collision)	(BPG 1.3.1)

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
Take COLREG measures	The ABS	must		initiate	action (if an imminent collision situation arises)	COLREG R7
Take COLREG measures	The ABS	must		notify	the SCC (if an imminent collision situation arises)	COLREG R7
Take COLREG measures	The ABS	must		perform	a steady course and speed (if the unmanned ship is the stand-on ship)	COLREG R17
Take COLREG measures	The ABS	must		detect	an avoidance maneuver of the other ship	COLREG R5
Take COLREG measures	The ABS	must		notify	the SCC (if an avoidance maneuver of the other ship is detected)	---
Take COLREG measures	The ABS	shall		transmit	a message to another ship to keep well clear (if the system doesn't detect an avoidance maneuver of the other ship)	---
Take COLREG measures	The ABS	must		notify	the SCC (if other ship does not act according to COLREGs)	---
Take COLREG measures	The ABS	shall		transmit	a message to other ships about its intentions (if an evasive maneuver is being performed)	COLREG R34
Take COLREG measures	The ABS	must		notify	the SCC (if the other ship has been passed well clear and the close quarters situation has been resolved)	---
Take COLREG measures	The ABS	must	offer SCC the possibility to	define	a specific collision avoidance maneuver, besides the one found by the ABS	COLREG R8
Take COLREG measures	The ABS	must	offer SCC the possibility to	initiate	a restriction of the "maneuver of the last moment"-function (if pilot boats, tug boats or similar are approaching)	COLREG R17 b
Take COLREG measures	The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
…	The ABS	must/shall	…	…	…	…

6.8 Conduct lookout (traffic)

Navigational sensors on board the UAS constantly gather data to generate a complete traffic picture of the vicinity of the ship. To do so objects are being detected, identified and tracked. This traffic assessment is supported by the CCTV picture. The legal foundation for these requirements can mainly be found within SOLAS, STCW, COLREGs and several IMO resolutions.

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
Provide radar/ARPA picture	The ABS	must	be capable to	receive	data from own ship sensors (radar/ARPA)	SOLAS Chapter V R19 2.3.2/2.3.3/2.7
Provide radar/ARPA picture	The ABS	must	be capable to	receive	information about ships and objects in own ships vicinity by radar/ARPA	SOLAS Chapter V R19 2.3.2/2.3.3/2.7

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
Provide radar/ARPA picture	The ABS	shall	offer SCC the possibility to	define	the radar/ARPA input parameters (if it is not automatically set)	SOLAS Chapter V R19 2.3.2/2.3.3/2.7
Identify targets	The ABS	must	be capable to	receive	information on aids to navigation from sea charts (e.g. lighthouses, buoys, coastlines)	STCW A-VIII/2 Part 4-1 (14-17)
Provide radar/ARPA picture	The ABS	must		detect	objects in vicinity (e.g. ships, aids to navigation, floating debris, PIWs) by radar/ARPA	STCW A-VIII/2 Part 4-1 (14-17)
Identify targets	The ABS	shall		identify	objects in vicinity (e.g. ships, aids to navigation, floating debris, PIWs)	STCW A-VIII/2 Part 4-1 (14-17)
Identify targets	The ABS	must		evaluate	the identified position of aids to navigation in comparison with the supposed position according to sea charts	STCW B-II/1 (11.1.1)
Identify targets	The ABS	must		identify	deviations between actual position of aids to navigation with supposed position	SOLAS Chapter V R19 2.1.3
Identify targets	The ABS	must		notify	the SCC (if discrepancies with the position of an aid to navigation is detected)	---
Identify targets	The ABS	must	be capable to	receive	data from own ship sensors (position data)	SOLAS Chapter V R19 (2.1.6)
Identify targets	The ABS	must	be capable to	receive	navigational warnings by NAVTEX	SOLAS Chapter IV Part B R7 1.4
Identify targets	The ABS	must	be capable to	receive	information about ships and objects in own ships vicinity by AIS	SOLAS Chapter V R19 2.4
Identify targets	The ABS	must	be capable to	receive	information on other ship's maneuverability	SOLAS Chapter V R19 2.4 COLREG Part C
Identify targets	The ABS	must	be capable to	receive	data from own ship sensors (acoustic information)	SOLAS Chapter V R19 (2.1.8)
Identify targets	The ABS	must		provide	enriched ECDIS information, containing traffic situation, objects etc. to other ABS processes	SOLAS Chapter V R19 (2.1.4)
Identify targets	The ABS	must	offer SCC the possibility to	access	enriched ECDIS information, containing traffic situation, objects etc.	SOLAS Chapter V R19 (2.1.4)
Identify targets	The ABS	must	offer SCC the possibility to	access	all surveillance data / information in a suitable manner	MSC.252(83)
Identify targets	The ABS	must	offer OBP the possibility to	access	information about the current traffic situation	COLREG R5 SOLAS Chapter V R19
Identify targets	The ABS	must		provide	a time frame for the data that is forwarded to the SCC or to other ABS processes	---
Provide CCTV picture	The ABS	must	be capable to	receive	data from own ship sensors (CCTV information: object detection)	COLREG R5
Provide CCTV picture	The ABS	must		detect	objects in vicinity (e.g. ships, aids to navigation, floating debris, PIWs) by	COLREG R5/R19

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
					CCTV	
Provide CCTV picture	The ABS	must	be capable to	evaluate	information about ships and objects in own ships vicinity by visual means (CCTV)	COLREG
Relay voice radio	The ABS	must/shall	be capable to	receive	Radio messages	SOLAS Chapter IV Part C R6.3/R12
Relay voice radio	The ABS	must/shall	be capable to	evaluate	Radio messages	SOLAS Chapter IV Part C R6.3/R12
Relay voice radio	The ABS	must/shall	be capable to	transmit	Radio messages	SOLAS Chapter IV Part C R6.3/R12 STCW B-II/1 (11.9)
...	The ABS	must/shall	...	...	...	...

6.9 Manage alarms and emergencies

Situations which are potentially threatening the safety of the ship are being managed within this process with strong connections to the SCC and other UAS processes. The legal foundation for these requirements can mainly be found within SOLAS, STCW, ISM-code, IAMSAR, and several IMO resolutions.

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
SAR	The ABS	must	offer SCC the possibility to	initiate	SAR mode	SOLAS Chapter V R33
SAR	The ABS	must	be capable to	perform	within a SAR operation according to IAMSAR	SOLAS Chapter V R33 IAMSAR
SAR	The ABS	must	be capable to	perform	search pattern	SOLAS Chapter V R33 IAMSAR
SAR	The ABS	must		initiate	search mode	SOLAS Chapter V R33 IAMSAR
SAR	The ABS	must		provide	information on the results of the search to SCC (if SAR is initiated)	SOLAS Chapter V R33 (1) IAMSAR
SAR	The ABS	shall		provide	live video stream to SCC (if SAR is initiated)	---
FtS	The ABS	must	be capable to	receive	a request for FtS action from other ABS processes	---
FtS	The ABS	must		evaluate	the situation continuously regarding the necessity to initiate a FtS procedure	---
FtS	The ABS	must		determine	the appropriate FtS procedure	---
FtS	The ABS	must		initiate	FtS continue on course with · safe (reduced) speed (if found appropriate)	---
FtS	The ABS	must		initiate	FtS fix position maneuver (if found appropriate)	??
FtS	The ABS	must		initiate	FtS emergency brake maneuver (if found appropriate)	SOLAS Chapter II-1 Part C R28
FtS	The ABS	must		initiate	FtS emergency anchoring maneuver (if found appropriate)	
FtS	The ABS	must		initiate	other FtS procedure (if found appropriate)	---

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
FtS	The ABS	must		notify	the SCC	---
FtS	The ABS	must		transmit	commands to other ABS processes to carry out FtS (if FtS is initiated)	---
FtS	The ABS	must	offer SCC the possibility to	initiate	FtS procedure of choice	---
FtS	The ABS	must	offer SCC the possibility to	initiate	return to normal operation	---
Incident on ship	The ABS	must	be capable to	detect	an anomaly in on-board system operation that may impact safe operation	ISM-Code
Incident on ship	The ABS	must	be capable to	receive	information on incidents (e.g. sensor identifies fire)	STCW A-VIII/2 Part 4-1 (18.7)
Incident on ship	The ABS	must	be capable to	receive	information on malfunctions of systems on board own ship	STCW B-II/1 (11.8)
Incident on ship	The ABS	must		evaluate	incidents or malfunctions (to determine e.g. severity, false alarm)	STCW B-II/1 (11.8) MSC.74(69) MSC.252(83)
Incident on ship	The ABS	must		initiate	suitable actions (if incident or malfunction message is assessed to be no false alarm)	IAMSAR ISM-Code Part A (1.4.5)
Incident on ship	The ABS	must		initiate	ship alarm system (if incident requires so)	SOLAS Chapter II-1 Part C R51/R52 STCW A-VIII/2 Part 4-1 (17.9 & 18.7) MSC.74(69)
Incident on ship	The ABS	must		initiate	FtS (if incident requires so)	---
Incident on ship	The ABS	must		notify	the SCC (if an incident has occurred)	---
Incident on ship	The ABS	must		provide	information about the incident to the SCC (if an incident has occurred)	SOLAS Chapter V R33 (2)
Other ship in distress	The ABS	must/shall	be capable to	receive	data from own ship sensors (radio messages related to ship in distress)	STCW B-II/1 (11.8)
Other ship in distress	The ABS	must/shall	be capable to	receive	data from own ship sensors (CCTV: indications related to a ship in distress)	---
Other ship in distress	The ABS	must/shall		evaluate	information related to a possible ship in distress situation	SOLAS Chapter V R33
Other ship in distress	The ABS	must/shall		identify	request for help by other ships	SOLAS Chapter V R33 (1)
Incident on ship	The ABS	must	offer SCC the possibility to	receive	information (if in incident has occurred)	SOLAS Chapter V R33
Other ship in distress	The ABS	must/shall		notify	the ship in distress that its distress call has been received	SOLAS Chapter V R33 (2)
Other ship in distress	The ABS	must/shall		notify	the SCC (if a distress call has been received)	SOLAS Chapter V R33
Other ship in distress	The ABS	must/shall		transmit	information about identified ship in distress to SCC	IAMSAR

Subprocess	System	Obligation	Trigger	Process word	Object	Legal Regulations
Other ship in distress	The ABS	must/shall	be capable to	receive	commands on how to assist the ship in distress from the SCC	IAMSAR
Other ship in distress	The ABS	must/shall		notify	the ship in distress about planned actions	IAMSAR
Other ship in distress	The ABS	must/shall		provide	assistance to a ship in distress (if suitable actions are possible)	SOLAS Chapter V R33 (1)
…	The ABS	must/shall	…	…	…	…

7. Interfaces of the Autonomous Bridge System

7.1 Interfaces with SCC

Autonomous ship navigation is conducted by the ABS which controls the movements of the UAS within strict limitations set by SCC parameters. Most situations the ship may encounter on the open seas will fall within a predefined frame of freedom and can therefore be dealt with independently. In case an especially challenging situation is developing, the shore operator will be notified and if no suitable solution can be found, human assistance is requested.

While the ABS is responsible to ensure the safe navigation of the UAS it is the SCC's function to monitor the unmanned and autonomous operation of the ship and intervene, if circumstances demand. To enable a thorough monitoring, a constant information exchange has to be ensured. Which tasks are performed by either the UAS or the SCC during autonomous operation mode has been explained within chapters 5 and 6 of this deliverable. The composition of information and update rate depends on the current ship status but can also be increased manually by the SCC operator. Additionally to the frequent submission of push information, specific data can always be requested by pull information.

During times of deep sea voyages the UAS will navigate autonomously and the SCC will be in remote monitoring mode. This means that as long as there are no unusual occurrences detected by the ship, only a relatively small amount of data is transferred along with 15 high level status indicator flags. They'll display the current status of all ship's major components, e.g. location, visibility, stability, propulsion and cargo. Each of those flags require a 2-bit code for indicating its status in green, yellow, orange or red color along with 1-bit code for acknowledging a flag. In case of a status change, additional related data will be automatically submitted along with the indicator update. Therefore, bandwidth requirements for SCC remote monitoring will be rather low, amounting to a few hundred bytes per interval. While the ship is in ocean transit data interchange will fully depend on satellite systems, such as Inmarsat, Iridium, Intelsat and also other VSAT providers. If communication connection should fail or be limited, the ship will still be able to continue safe operation without human supervision. In such

a case the ship will revert to and follow one of the preprogramed FtS-strategies to cope with arising situations.
In work package 4 and 7 the communication architecture and SCC interface issues will be elaborated more in detail.

7.2 Interfaces with EAS

When operating in autonomous mode, the UAS is controlled by two key on-board components. The AEMC is responsible for operating the engine room and its components while the ABS takes care of all navigation-related matters. To fulfill their task it is necessary for these two entities to exchange their data.
The interface between the ABS and the AEMC must ensure a sharing of measuring values from the EAS and must be able to submit control commands from the ABS to the AEMC. It is not yet clear so far whether the AEMC and the ABS are physically separated hardware connected through a network, virtualized systems on the same hardware or software modules on one system. Therefore, the selected interface technology must be able to handle all three solutions. That means that an interface for inter-process communication over network is needed. Examples for this so called RPC are CORBA or Java RMI. In CORBA for example an interface definition language is used to specify the signature of functions and the structure of data. Afterwards, the defined interface functions and data are translated into a native programming code. The ABS will now have the ability to call functions from the AEMC to request values or to trigger a command. The ABS doesn't need the knowledge about the physical hardware environment because this is handled by the CORBA transportation layer.
The RPC technology enables all controllers in the whole network to request values from the AEMC and this is not limited to the ABS. The chosen RPC technology should be standardized by an international consortium and not a proprietary solution. The standardization will facilitate later additions or changes of the system and guarantee the interoperability of different controllers. The structure of the autonomous engine room is subject to work package 6 where information needs and interfaces will also be discussed.

8. Identification of research needs

According to the European Waterborne Technology Platform, a UAS is described as a ship with: „next generation modular control systems and communications technology that will enable wireless monitoring and control functions both on and off board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control“ /32/. To develop a concept for such a ship, engaged in unmanned and autonomous deep-sea operation, is precisely what the MUNIN-project is aiming for.

Currently, a number of projects from different stakeholders are investigating how to improve safety and efficiency in ship operation. The significant technological advancements which have been made during the last years, particularly in the field of wireless world-wide communication, have given rise to new approaches of maritime information exchange. The general development of the IMO's e-Navigation strategy and the EU's e-Maritime initiative as well as projects such as e.g. ACCSEAS /33/, eLORAN /34/, MONALISA /35/, PiLoNav /36/ and their follow-ups may not aim for the unmanned and autonomous ship but their outcome can certainly contribute to the MUNIN concept.

A great task of investigation will need to be done in the field of sensor technology. Substituting the on-board human lookout by an Advanced Sensor System ASS and an SCC operator creates certain challenges. The sensor fusion concept which has been mentioned in chapter 5 of this paper will further investigate this topic within this project's D5.3 Sensor systems for automated detection within the next months. Most of the sensors which will have to be employed are generally already available today. Some may require adoption for maritime purposes, though. Also, the number of sensors on an UAS is expected to be much greater than on an equivalent conventional ship.

In the area of traditional navigational sensors for determining e.g. position, speed and water depth it won't be problematic to find suitable measuring instruments. It will be interesting though, if an automated sextant can be employed on an UAS to use celestial navigation as an additional means for positioning. The situation for sensors monitoring ship motions, hull stresses and tank ullages is quite similar. There is a quantity of adequate devices and applications which can be fitted to match the degree of redundancy which is required for safe UAS operation. The actual research need in this field lies within the fusion of sensor readings to produce resilient data values. Investigation will also need to be done in the areas of cargo and alert monitoring. Solutions for automatic surveillance of all ship spaces for detection of e.g. cargo damages, ignitions or water ingress will have to be found. Much more challenging will be the question of how to replace the human lookout. Many efforts are currently being made by the maritime electronic industry to develop approaches towards a holistic bridge design, combining data from AIS, ECDIS, radar/ARPA and all other navigational devices. This creates a common perception of the surrounding of the ship to support the OOW in his watchkeeping duties. With the human cognitive and interpretative skills this perception is completed. On an unmanned ship the human acoustic cognition can be replaced by a system of microphones as used on closed bridges of many passenger ships. Research would have to be done in the field of audio processing to be able to monitor outside noises and sounds as well to conduct voice radio watch. Visual cognitive tasks will be carried out by a CCTV-system which hasn't been employed in merchant shipping so far. It will produce visual pictures of the ship's surrounding. The quality of image processing and its abilities in object detection and identification are essential in substituting a bridge navigator by an ASS and an SCC operator. This leads to the question of how the interaction between the UAS and the SCC should be organized and what degree of autonomy can be granted to an unmanned ship.

Beyond that, the MUNIN concept will take bridge integration one step further, incorporating assistance systems for weather routing, stability control and collision avoidance. Today's available solutions will have to be closely examined and enhanced from a tool that gives only guidance to a mariner to a tool that is actually capable to make decisions and to take action. Within the limits of SCC-set parameters the UAS would then be able to plan and adjust its own track depending on external factors. To do so, a ship domain for the UAS to operate within will have to be elaborated and defined. This domain can be described as the area surrounding a ship which should be kept free of other ships and objects. The criteria for this framework of navigational thresholds depend on the one hand on legislative requirements and on the other hand on the hard-to-grasp term of good seamanship. To get a hold of exactly that, a number of further focus group interviews with nautical professionals and shipping experts will be necessary. Another related topic raising many questions concerns the handling of distress and emergency situations. Analysis is necessary on how to deal with states of alarms and emergencies on the UAS itself but also how the UAS can recognize and assist other ships in such conditions. This includes also the issue of rescue of an over-board or shipwrecked person.

Another matter necessitating further investigation is the UAS' communication procedures. As direct interaction with a manned station might be difficult to realize, it has been decided that communication will be relayed to the SCC via satellite link. This is only one point outlining the importance of a firm and stable connection between ship and shore. First steps into this direction have been made in this project's D4.3 Evaluation of ship to shore communication links. Further investigations will be necessary though, also with regard to data security. From the question of how to assure robust ship-shore information exchange derives the question of what information to exchange. It is clear that the variety of data and the interval at which this data is transmitted depends on what phase of voyage and what operational mode the ship is currently in. During ocean transit, the UAS would typically be in autonomous operation, leaving the SCC in remote monitoring. Within this mode, a set of four flags indicate the status of the ship to the shore operator. General ideas about the ship-shore information exchange interface have been expressed during above mentioned focus group interviews. Now, more precise processes with exact values and thresholds will have to be elaborated for this concept.

Following this deliverable and based on its results D5.4 Autonomous deep sea navigation system concept will be established, taking also into account the current state of all other project work packages.

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