ESABALT D3.1

State-of-the-art Analysis and Technology Evaluation: Initial Finding Report

REVISION LIST

Date	Issue	Notes
16/05/2014	1.0	Template distributed.
08/08/2014	1.1	Partner contributions consolidated and edited by R. Guinness and S. Thombre
02/03/2015	1.2	Consolidated version prepared for final contribution from partners
09/03/2015	1.3	Final version uploaded to BONUS

DELIVERABLE DETAILS:

Deliverable number:	3.1
Work package leader:	FGI
Deliverable name:	State-of-the-art Analysis and Technology Evaluation: Initial Finding Report (Short title: ESABALT State-of-the-art Analysis)
Nature of the deliverable:	Report
Dissemination level:	Public
Delivery month:	T12
Date submitted:	09 March 2015

Contents

1 Introduction

The purpose of this report is to capture the initial findings performed as part of Work Package 3 (WP3) *State-of-the-art Analysis and Technology Evaluation*. The activities of WP3 will continue for a total of twelve months, concluding in March 2015. Thus, with this report we aim to consolidate the state-of-art and background information collected concerning technologies and systems under study or implementation in ESABALT. The results of this study can therefore be used to determine the future areas of focus for the remainder of the project. As stated in the ESABALT Description of Work (DoW), the objective of WP3 is to review state-of-the-art technologies and solutions relevant to the ESABALT concept and evaluate the feasibility of utilizing them in the developed ESBALT solution.

The work is divided into seven separate tasks, as follows:

- **Task 3.1** Review of the maritime safety approaches
- **Task 3.2** Analysis of navigation technologies
- **Task 3.3** Evaluation of Earth Observation technologies
- **Task 3.4** Communication technologies evaluation
- **Task 3.5** Evaluation of AIS sensors
- **Task 3.6** Evaluate other existing user-driven solutions for enhancing transportation safety and situational awareness and their applicability to the maritime environment
  Task 3.7 Feasibility of the crowdsourcing approach for marine information gathering

Accordingly, this report contains one section per each of these tasks. These sections are preceded by a short section outlining the analysis approach adopted for this research. After each of the task-related sections are presented, the conclusion section summarizes our findings thus far in WP3 and outlines our research activities for the remainder of the work package.

2 Analysis approach

The analysis approach taken in this research was to divide the subject matter into seven distinct categories, according to the task definitions listed above, and to distribute these subject areas among the ESABALT Consortium, according to the subject matter expertise of each of the partners and their respective project participants. In several of the subject areas, more than one partner was identified as having strong expertise, so these subjects were researched in collaboration between two or more partners. In several cases, the subject area was further subdivided into distinct sub-categories and then distributed to different partners/personnel accordingly. These sub-categories will be self-evident in the sub-sections to follow.

Each assigned partner was given the freedom to research the subject matter independently and according to its own desired techniques and style. Guidance was given that research and analysis should be as broad as possible at this stage in the work package. In other words, the research should address all technologies that could be potentially utilized in the ESABALT solution. Thus, the only boundaries in scope that each partner had were the assigned subject areas. Emphasis was placed on <u>identification</u> and <u>description</u> of potentially relevant technologies. In addition, other relevant research projects were to be identified and summarized. Most partners used open literature and/or internet sources to assess the state-of-the-art, as well as their own subject matter expertise, which in some cases included industrial knowledge that may or may not be known publicly.

The goal of the ESABALT project is to study the feasibility of enhancing situational awareness through the integration of various navigation, communication, and remote sensing technologies. Recently several FGI researchers from the Department of Navigation and Positioning went aboard Viking Line’s M/S Amorella, operating between Turku and Stockholm, to gather data and interview Amorella’s crew. We temporally installed several radio antennas to collect signals from Global Satellite Navigation Systems (GNSS), cellular networks, and even digital TV and FM radio towers. We collected also information from the Ship’s own electronic systems. The data will be used to study how available information and radio signals can best be utilized for crowdsourcing, navigation and communication in the archipelago area. The data is currently under analysis and hence will be explained in more detail in the ESABALT Progress Report 1.

Lastly, a set of twenty-nine questions to facilitate the analysis of the state-of-the-art were prepared by one partner and agreed upon by all partners. The purpose of these questions was to provide further guidance as to the type of information that should be gathered in the research. To some extent the aim was also to provide some level of standardization of the information collected across the different subject areas. Given the diverse nature of the subject areas, however, it was understood that this was a challenging goal. Also, due to the preliminary nature of this research phase, it was further understood that not all questions, even if applicable to a given subject area, could be yet answered to any degree of authority. One particular reason for this is because the ESABALT system itself has not been specified to any level of detail, as this is primarily future work for Work Package 4. Thus, it is to a large extent premature to determine the feasibility or applicability of any particular technology vis–à–vis “the ESABALT system.”

3 Review of maritime safety approaches

3.1 Existing principles, systems and devices

3.1.1 Introduction

SOLAS (Safety of Life at Sea) convention sets the minimum safety requirements for the merchant ships.

The first SOLAS version was adopted in 1914, in response to the Titanic disaster, the second in 1929, the third in 1948, and the fourth in 1960. The 1974 version includes the tacit acceptance procedure - which provides that an amendment shall enter into force on a specified date unless, before that date, objections to the amendment are received from an agreed number of parties.

As a result the 1974 Convention has been updated and amended on numerous occasions. The Convention in force today is sometimes referred to as SOLAS, 1974, as amended.

The main objective of the SOLAS Convention is to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety. Flag States are responsible for ensuring that ships under their flag comply with its requirements, and a number of certificates are prescribed in the Convention as proof that this has been done (www.imo.org).

In addition to SOLAS, IMO and classification societies set requirements for different types of vessels and their systems.

Coastal vessel traffic is monitored from land to safeguard and protect people, property and the environment. Different issues are observed and administered by different land based organizations. For example the national coast guard leads oil spill cleaning and fishing vessel controls from a land based command central.

Another example of a land based organization monitoring and administering close to shore vessel traffic are VTS-centers (Vessel Traffic Service). A VTS-center separates vessel traffic in narrow fairways so that collision risks are minimized. It also serves for sending out pilots that guides foreign ships entering a new harbor. Other examples of such organizations are MRCC (Maritime rescue coordination center, land based operations centrals for managing distress at sea) and command centrals for seaborne police and ambulance.

Many of the safety systems and systems for situational awareness which are used from a land point of view are the same as the ones found onboard ships. The most central means for situational awareness from a land point of view are remotely installed radars and CCTV, VHF and AIS.

Information from remotely installed radars along the coast, radio masts for receiving VHF communication and AIS information and CCTVs installed on key locations are a gathered a centralized to command centrals covering large geographical areas.

Although analog radio (i.e. VHF) communication is the most widespread form for communication between land and vessels at sea, certain nations has adopted own methods for telecommunication. These are used by nations authorities to communicate internally and with other national authorities (e.g. police, military, coast guard, etc.). Modern and advance national telecommunication systems are digital which allows for encryption and better sound quality. Examples of such systems are RAKEL in Sweden, VIRVE in Finland, Nødnett in Norway and SINE in Denmark.

From a national military defense point of view situational awareness differs from the civil application. Here the aim is on detecting vessels not wanting to be detected. In addition to the previous stated systems, more advanced detection methods are used such as infrared, magnetic, thermal and acoustic systems.

3.1.2 Marine VHF radio

Marine VHF radio communication is the most central mean of communication in the maritime industry. VHF is installed on most between ships and land based marine infrastructure (harbors, locks, marinas, coast guards, etc.) as a combined transmitter and receiver or as a sole receiver (i.e. listening only). VHF radios can be implemented as a stationary installation, e.g. on a ship bridge, or as a mobile as a hand-held walkie-talkie.

VHF, abbreviation for Very High Frequency, corresponds to the frequency range which the communication is broadcasted on. The VHF operates on the 156.0 to 162.025 MHz band.

Voice calls are made on standard frequencies, i.e. channels, which are dedicated to different purposes. Channel 16 (156.8 MHz) is the international calling and distress channel while channel 6 and channel 8 are widely used for ship-to-ship communications. Large ships and land based monitoring institutions usually have several VHF radios installed: one set permanently to channel 16 and others used to communicate on various channels.

VHF is also used to transmit other information than voice calls. AIS, see chapter 3.1.3, and uses VHF radio to communicate ID, position and speed to other vessel.

3.1.3 Electronic Chart Display and Information System

Important navigation equipment is ECDIS (Electronic Chart Display and Information System).

ECDIS is a computer-based navigation information system that complies with IMO regulations and can be used as an alternative to paper nautical charts. IMO refers to similar systems not meeting the regulations as Electronic Chart Systems (ECS).

ECDIS system displays the information from electronic navigational charts (ENC) and integrates position information from position, heading and speed through water reference systems and optionally other navigational sensors (Weintrit, 2009).

ECDIS will be compulsory system based on vessel type according to schedule presented in the below diagram.

3.1.4 Automatic Identification System (AIS)

AIS (Automatic Identification System) is one safety related sub system in vessels. The Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel tracking services for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. When satellites are used to detect AIS signatures then the term Satellite-AIS (S-AIS) is used. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport.

Information provided by AIS equipment, such as unique identification, position, course, and speed, can be displayed on a screen or an ECDIS. AIS is intended to assist a vessel's watchstanding officers and allow maritime authorities to track and monitor vessel movements. AIS integrates a standardized VHF transceiver with a positioning system. Vessels fitted with AIS transceivers and transponders can be tracked by AIS base stations located along coast lines or, when out of range of terrestrial networks, through a growing number of satellites that are fitted with special AIS receivers which are capable of deconflicting a large number of signatures. IMO requires AIS to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 or more, and all passenger ships regardless of size (IMO, 2015).

3.1.5 Bridge Alarm and Alert Systems (FURUNO)

A Bridge Navigational Watch Alarm System, abbreviated BNWAS, is an automatic system which sounds an alarm if the watch officer on the bridge of a ship falls asleep, becomes otherwise incapacitated, or is absent for too long a time. The BNWAS is automatically engaged when the ship's autopilot is activated.

BNWAS is compulsory system in all passenger vessels and starting in July 2014 in all ships larger than 150 tones.

Bridge Alert Management (BAM) helps to improve the handling, forwarding and presentation of alerts. In doing so, it harmonizes the priority, classification, handling, distribution and presentation of alerts, meaning that the bridge team can devote its full attention to the safe operation of the ship and immediately identify any alert situation requiring action to maintain the safe operation of the ship. The IMO recommends the use of bridge alert management systems to governments for those ships flying their flags. BAM installed on bridges should at least conform to the performance requirements stated in the annex to IMO Resolution MSC.302(87) (www.bsh.de).

3.1.6 Global Maritime Distress and Safety System GMDSS

The Global Maritime Distress and Safety System (GMDSS) is an internationally agreed-upon set of safety procedures, types of equipment, and communication protocols used to increase safety and make it easier to rescue distressed ships, boats and aircraft.

GMDSS requirements apply for vessels over 300 gross tonnage.

GMDSS includes emergency position-indicating radio beacon (EPIRB), Navtex, Inmarsat, MF/HF/VHF radios, DSC (digital selective calling) and SART equipment.

GMDSS requirements are different for areas A1 – A4.

For smaller boats and personal safety can be used PLB (personal location beacon) equipment. PLB sends user location via satellite to the authorities.

In big vessels redundancy is built in critical systems. Eg. navigation system has at least two radars, position equipment, gyros and ECDIS processors, which increases safety of navigation in malfunction situations.

3.1.7 Radar

Another important navigation safety system onboard is radar. Normally in large vessels at least one X-band radar and one S-band radar are installed.

Radar system can be integrated with the ECDIS so that routes, safety zones and user charts are transferred to radar. Radar is important collision avoidance system which provides alarms if dangerous targets are too close to the ship.

Chart radar integrates radar and ECDIS functionalities into one system which has operating modes for chart, radar and chart+radar correspondingly.

For the ice-going ships ice radar has become important safety related equipment. Ice radar improves ice navigation capability of the vessel by visualizing local ice conditions and even icebergs.

In the high end vessels integrated navigation system (INS) integrates all separate systems into one platform which is easier to use than separate systems. IMO has generated rules also for the INS systems. Trend is proceeding towards more and more integrated systems which may improve safety in the future.

3.1.8 Other specialized ship navigation systems

Sound reception systems (so called elephant ears) are acoustical electronic navigational aids to enable officer on the watch to hear outside sounds signals inside a totally enclosed bridge as required by the rules.

Thermal cameras can be used as navigational aid especially in dark environment. It can also be valuable aid when navigating in tough ice conditions trying to find route through solid ice. Especially thermal camera integrated with radar and chart information can bring lots of added value in safe navigation.

3.1.9 CCTV

CCTV (closed-circuit television) is a situational awareness system used mainly by land based vessel monitoring centres to get visual information from remote locations. This can be used to discover, identify and locate vessels not using AIS-transponders, VHF-communication, etc., in a narrow and busy fairway. Information from the CCTV is presented visually on a screen in the land based monitoring centre which then can communicate the information to the relevant receivers, e.g. a large approaching cruise liner.

3.1.10 Vessel Monitoring System VMS

Vessel Monitoring System VMS is a system used within commercial fishing. It is intended primarily for fisheries regulatory organization to monitor position, speed and direction of fishing vessel at a given time. Within the EU it is a legal requirement for fishing vessels longer than 15 meters.

Information from the VMS system can, similarly to the AIS-information, is plotted on an electrical navigational chart. However, information from the VMS system is not public since it is commercially sensitive, e.g. disclosing good fishing spots. Another difference from the AIS is that it is communicated through satellite, e.g. Inmarsat-C in Sweden and Denmark.

3.1.11 Other onboard, on shore and off shore specialized navigation systems

The pilot navigational systems (PNS) are intended for navigating in restricted areas, often referred to as pilot navigation, which consists in three tasks that the system has to perform:

- planning a safe maneuver,
- determination of a ship’s position with a specific accuracy,
- ship movement control enabling safe performance of a planned maneuver.

The need to build such systems results from the specific character of navigation in a restricted water area, e.g. fast changes of ship’s position in relation to land objects, navigational obstructions and others.

Docking systems are developed to assure the safety of the vessel, cargo and the marine environment during berthing and unberthing maneuvers, particularly by ships carrying dangerous cargo (e.g. LNG) in heavy weather conditions. These systems provide accurate data on ship’s hull position and speed relative to the berth. The required accuracy can be obtained by using GNSS receivers working with an external source system such as the RTK system or by means of a measurement system mounted on the berth, e.g. a laser system.

Dynamic Positioning Systems (DP) are used for precise ship maneuvering:

- maintaining ship’s operating position;
- moving a ship to another position maintaining a specific low speed;
- controlling the position, speed and course during ship’s operation.

Automatic positioning is based on reference systems, using electric power units, bow and stern thrusters, azimuth thrusters, the main propulsion and rudder, taking account of weather conditions.

Weather routing systems. The purpose of weather routing (navigation) is the determination of an optimal route of an ocean-going vessel based on the present and predicted weather data, taking into account ship's speed and maneuvering characteristics.

The ship's route is determined on such criteria as ship and cargo safety as well as economic criteria (e.g. voyage time, fuel consumption). Therefore, the optimization of a sea route depends to the group of multicriteria problems. Until recently, only land-based centers used such systems. At present, the number of those installed on board is growing.

3.1.12 Future of maritime safety systems - navigational applications on smartphones and touchpad tablets

A combination of the smartphone revolution together with increasing wireless internet speed and access have made way for a new means for navigation at sea. Smartphones and touchpad tablets are being increasingly used for close to shore navigation, e.g. in archipelagos or lakes, by pleasure boat owners. Development of navigational applications for smartphones has in a few years gone from solely electrical navigation charts to now covering the same functions as a dedicated chartplotters. Seapilot (Seapilot, 2015) and Navionics (Navionics, 2015) are examples of developers of such navigational applications for iPad, iPhone, windows 8 and android.

In addition to the basic navigational charts and overlay GPS-position marker, the applications include other chartplotter functions such as man overboard function, route-planning, tracking, waypoint markers etc.

Seapilot is even the first navigation app to include AIS and AIS weather data for smartphone navigational applications. A comparison of traditional chartplotters vs. smartphones and touchpad tablets for navigation at sea was made in a journal given out by the Swedish Maritime Administration in summer of 2013 (*Sjörapporten*, nr 3, 2013, p. 6-11).

3.1.13 Gaps

Biggest gaps in safety approaches are due to tough competition situation in marine business. Several vessels are old and have just minimum requirements equipment onboard. Some equipment is broken for long time before service.

Vessel's crew sometimes has poor language skills and no training to operate vessel systems. Also attitude towards safe navigation is not always adequate. Even drunk crew has been reported in several cases also in Baltic Sea.

Charts for ECDIS are often not updated often enough for all navigated areas.

Winter time with tough ice conditions is real challenge for many vessels in Baltic Sea. Poor maneuverability of old vessels not designed for thick ice and archipelago routes is difficult combination regarding the safe navigation.

Two study visits were made during the information gathering phase of land based navigational systems. One at a VTS-center managing vessel traffic on the east coast of Sweden and the other at the Swedish coast guard command central in Stockholm. When the operators were asked about gaps in the systems most answered that they did not have any. They believed that their routines and sources for information gathering worked well.

Our guide at the Swedish coast guard even thought that there could be a greater risk for them using an open system like ESABALT to end up “chasing ghosts” as he described it. He thought that a better application of such a system would be a communication channel to pleasure boat owners. In other words rather being a user that provides information the system which pleasure boat owners, who have less access to communications systems like Radar, VHF or AIS-information, would receive on their e.g. smartphones.

3.2 R&D Projects relating to ESABALT

3.2.1 Ariadna Maritime Volumetric Navigation System – ARIADNA

EU 7th FWP (Seventh Framework Programme), Transport themes: Intelligent transport systems, Transport management, Water transport (sea & inland) (key theme), Security and Safety.

Start date of project: 01.11.2009. Duration: 36 months.

The goal of the project ARIADNA (ARIADNA, 2015) is to design a new concept and build a new series of navigation support systems which facilitate:

- optimization of the use of maritime and inland infrastructures,
- safe navigation in dense traffic situations in ports, rivers, channels, lock and port access areas,
- improvement of traffic separation schemes,
- improved risk control, including grounding,
- efficient and environmentally-friendly operations.

ARIADNA based products can be also useful to avoid human error in navigation. The new system provides warning and manoeuvring support for collision avoidance, as well as risk and warning assessment to vessel and navigation control systems in different maritime scenarios such as channels, port access areas, narrow inland waterways and congested areas.

ARIADNA system aims at the implementation of the Volumetric Navigation System (VNS) for maritime and inland navigation according to the following preconditions:

The system combines data on navigation, position and vessel characteristics with time information about relative positions in regard to vessels and infrastructures that are located in its surroundings.

Through the usage of VNS, all vessels share information in order to be part of a collaborative navigation network.

ESABALT project could benefit from Ariadna Project by focusing on system validation methodology and road map development. Ariadna Project outcomes may be useful also in economic and non-economic viability analysis of ESABALT system.

3.2.2 Baltic Master I

EU Project, Baltic Sea Region Programme.

Duration: 1 July 2005 – 31 December 2007

The main objectives of Baltic Master (Baltic Master I, 2015) were:

- to increase the influence of the regional governments and the local authorities on matters of maritime safety. The project defines their ability to participate more effectively.
- to develop transport and communications within a framework of maritime safety, taking into account the diversity of activities in the Baltic Sea.
- to increase preparedness for preventing and managing a catastrophe, through integrating local and regional zones in the planning and implementation processes.

Baltic Master aimed to improve maritime safety by integrating and bringing forward local and regional perspectives. This included measures to improve the prevention and the preparedness for ship accidents.

Maritime safety in a wider perspective, including regional development and spatial planning, was also investigated further.

The project consisted of four work packages. Each work package entailed several activities and outcomes, for example scenarios, think tanks, conferences, studies and reports. The four work packages were:

- Preparedness and Division of Responsibility
- Safe Transportation at Sea
- Sustainable Spatial and Regional Development
- Communication and Dissemination

The interesting outputs for the ESABALT project are ship safety analysis in Baltic Sea region and The most interesting outputs for the ESABALT project are ship safety analysis in Baltic sea region and an integrated model of navigational safety on Baltic sea.

3.2.3 Baltic Master II

EU Project, Baltic Sea Region Programme 2007-2013.

Duration: 25 January 2009 – 25 January 2012

The project Baltic Master II (Baltic Master II, 2015) continues where its predecessor Baltic Master.

Chosen Baltic Master II topics:

- Communication and Information (WP2)
- Improved land-based response capacity to oil spills at sea (WP 3)
- Enhanced prevention of pollution from maritime transport (WP4)

The most interesting outputs for the ESABALT project are reports on costs associated with a major oil spill and review of existing prognoses for the development of marine traffic in the Baltic Sea Region.

3.2.4 COSINUS Cooperative Vessel Guidance for Nautical Safety

German R&D project.

Start Date 01.11.2013. End Date 31.10.2015

The research project COSINUS (COSINUS, 2015a) (COSINUS, 2015b) investigates the integration of on-board navigation systems with maritime traffic control systems on shore. Cosinus is part of the open research platform eMIR - eMaritime Integrated Research platform - and an associated project of the research center "Critical Systems Engineering".

The project is aimed on “the generation of consistent situational awareness of staff on board and on shore in order to avoid collision and grounding despite continuously growing density of maritime traffic”. Central research topics are adaptive data communication and compression, manoeuver planning and simulation, exchange and fusion of manoeuver, route, weather, hydrologic and bathymetric data as well as new adaptive human-machine interfaces. It can be concluded on the basis of the information available that the project objectives are partially common with ESABALT. Therefore Cosinus project outcomes may be useful in economic and non-economic viability analysis of ESABALT system.

3.2.5 EfficienSea

EU Project, Baltic Sea Region Programme 2007-2013

Duration: 2008.10 – 2012.01

Main outputs of EfficienSea (EfficienSea, 2015) project:

- competence and recruitment challenges,
- e-Navigation,
- vessel traffic data and maritime planning,
- dynamic risk management.

Modern technology on the vessel bridge provides a lot of information that is supposed to help the navigator. But part of the information is unorganized, and there is a lack of standards. This can lead to confusion. There is an overflow of information on the bridge that could lead to accidents.

With e-Navigation (WP4) a new standard for organizing the information is developed, providing for better means of navigation. One system integrates all the necessary information to give the right information at the right time, filtering out everything that is irrelevant for safe navigation. e-Navigation is an evolutionary and dynamic concept that will continue to develop as new user needs arise and emerging technological opportunities become available.

Work Package 4 provides the Baltic Sea countries and the European community with a comprehensive best practice demonstration of the e-Navigation concept in order to facilitate the further development and full scale implementation of the concept.

This encompasses establishing one or more e-Navigation trial zone(s) where service providers can deploy and test trial versions of their products and services, and where these can be assessed by real users. Such a best practice demonstration will help prepare and mature as many stakeholders as possible for undertaking their roles in the future full scale deployment of e-Navigation.

The most interesting outputs for the ESABALT project are:

- e-Navigation,
- vessel traffic data and maritime planning.

Situational awareness, which is the main topic of ESABALT project, highly depends on availability of information. E-Navigation standardizing navigational information, which makes it more efficient.

Vessel traffic data are crucial for avoiding collision and therefore for improving situational awareness.

3.2.6 EMAR e-Maritime Strategic Framework and Simulation based Validation

7th FWP (Seventh Framework Programme), Programme Cooperation: Transport.

Start date: 1st January 2012. Time scale: 3 years

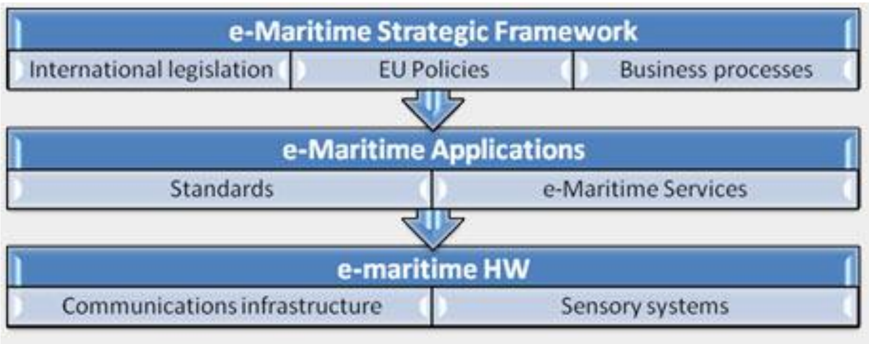
The EMAR project (EMAR, 2015) aims to empower the European maritime sector in offering efficient quality shipping services fully integrated in the overall European transport system over an upgraded information management infrastructure.

The EMAR approach will facilitate extensive participation of the European maritime public, business and research community in a knowledge development process leading to the specification of the e-Maritime Strategic Framework.

Aims:

- A target operational model for Maritime Transport (i.e. a description of processes, actors, rules, information flows and other domain entities) pertaining to common industry interests (positioning, innovation, sustainability performance) and business benefits (efficiency and quality) to be realized in the short or long term.
- A comprehensive software infrastructure to support the management and implementation of the e-Maritime Strategic Framework by providing:
    - a repository (a storeroom) from where e-Maritime Applications and Services may be downloaded,
    - a 'run-time' environment that supports operation and interaction of the e-Maritime Applications
    - a software development environment for production of additional e-Freight Applications and to integrate them with existing ones.
- A broad range of typical e-Maritime services such as security and safety management, legislation and regulation compliance, shipping, port operations, and transport logistics.

The above will be part of and evolve into the next generation e-Maritime infrastructure aimed at maintaining cohesion between EU Policy and Business Processes (represented by the e-Maritime Framework) and e-Maritime Applications by maintaining relationships as shown in the following diagram.



3.2.7 MARNIS - Maritime Navigation and Information Services

EU Project, 6th FWP (Sixth Framework Programme)

Duration: 2004.11 –2008.10

MarNIS (MARNIS, 2015) aims to establish a maritime navigation information structure in Europe. SafeSeaNet is a structure designed by DGTREN for the implementation of Hazmat and Waist directives. MarNIS aims at information exchange to improve and create seamless intermodal transport. MarNIS deals with functional and technical requirements of information systems. A structure will be developed called the Preventive and Remedial Services. It includes VTM at sea and improves the efficiency of SAR operations. MarNIS aims to safety, security and efficiency and intermodality of ports. Security will be discussed in the proposal. MarNIS addresses information exchange with regard to vessels. Reporting of positions and destinations of vessels need to be carried out semi-automatically. Nevertheless a lot of information is required by state agencies on shore such as customs, border police and PSC inspectors.

Key results include:

- Maritime operational services (MOS)
- Safeseanet++
- Single window/electronic port clearance (EPC)
- Marnis node and port community systems (PCS)
- Marnis broad band platform

From point of view of the ESABALT project two results are particularly interesting:

- Maritime operational services (MOS), which is a management system for VTS and SAR
- Marnis broad band platform, which is efficient satellite platform for communication.

3.2.8 Mona Lisa Motorways & electronic navigation by intelligence at sea

EU Project: Trans-European Transport Network (TEN-T)

Duration: 1st September 2010 - 31 December 2013

MONALISA (MONALISA, 2015) is a Motorways of the Sea project which aims at giving a concrete contribution to the efficient, safe and environmentally friendly maritime transport. This is done through development, demonstration and dissemination of innovative e-navigational services to the shipping industry, which can lay the groundwork for a future international deployment. Quality assurance of hydrographic data for the major navigational areas in Swedish and Finnish waters in the Baltic Sea contributes to improving safety and optimization of ship routes.

ESABALT project could benefit from Monalisa Project outcomes. Activity 1 “Dynamic and Proactive route planning" should solve transmission between ship and shore with route-updating procedure. Idea of information exchange between different actors should be utilized in ESABALT project.

3.2.9 Mona Lisa2 Motorways & electronic navigation by intelligence at sea

EU Project: Trans-European Transport Network (TEN-T)

Duration: 2013.11 --2015.12

Increased focus on safety of navigation.

MONALISA 2.0 (MONALISA 2.0, 2015) aims at contributing to a continuous improvement and development of efficient, safe and environmentally friendly maritime transport in the European Union by implementation of a series of measures in accordance with the EU's transport policies.
ESABALT project could benefit from Monalisa 2 project by focusing on implementation concrete pilot actions and studies that shall foster deployment of new maritime services and processes. These processes shall be (if possible) included in ESABALT action like integration of route planning tools with additional environmental information and maritime spatial planning for the purpose of improved maritime safety and environmental protection.

3.2.10 MUNIN Maritime Unmanned Navigation through Intelligence in Networks

EU 7th FWP (Seventh Framework Programme).

Duration: Start date 01.09.2012. End date 31.08.2015

The project MUNIN (MUNIN, 2015) to develop and verify a concept for an autonomous ship, which is defined as a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore side control station

Within MUNIN a consortium of eight partners led by Fraunhofer CML with scientific and industrial background will reflect upon operational, technical and legal aspects in connection with the vision of an autonomous ship. Solutions for e.g. an autonomous bridge, an autonomous engine room, a shore side operation centre and the communication architecture linking vessel and a shore operator will be developed and verified. Besides this long term goal of an autonomous ship MUNIN's results will also provide efficiency, safety and sustainability advantages for existing vessels in short term. This includes e.g. environmental optimization, new maintenance and operational concepts as well as improved bridge applications.

The main challenges (end of project – 31.08.2015) are:

- develop a feasible and useful IT architecture for autonomous operation,
- analyze the tasks performed on today's bridge and derive a concept for an autonomous bridge,
- examine the tasks in relation with a vessel's technical system and develop a concept for autonomous operation of the engine room,
- define the processes in a shore side operation center required to enable a remote control of the vessel,
- validate the feasibility of the developed solutions combined into the concept of an autonomous and unmanned vessel and
- identify and investigate legal and liability barriers for unmanned vessels.

As long as there are no autonomous vessels at seas, as long results of a/m project will not be useful for ESABALT.

3.2.11 NAVTRONIC Navigational System for Efficient Maritime Transport

NavTronic

EU 7th FWP (Seventh Framework Programme), Transport themes: Intelligent transport systems, Transport management, Water transport (sea & inland) (key theme), Assessment & decision support methodologies.

Duration: 2009.10 – 2012.09

The objective of NAVTRONIC (NAVTRONIC, 2015) project is to develop a sail planning system to help sea masters optimise these criteria. The proposed solution will mimic the current human sail planning process. Proposed in this project system shall automatically and continuously compute and communicate optimized sail plans to a vessel. Knowledge gained from this project shall be utilized in ESABALT project. Especially function of safe way/route might have similar properties.

3.2.12 SAFEWIN Safety of winter navigation in dynamic ice

EU 7th FWP (Seventh Framework Programme) TRANSPORT

Duration: 2009-09-01 to 2013-08-31

SAFEWIN (SAFEWIN, 2015) aims to develop an efficient ice compression and ice dynamics forecasting system which is precisely aimed in increasing the safety of winter navigation in dynamic ice conditions. This system is particularly efficient in case of large, AFRAMAX size or larger, oil tankers navigating in the Baltic, Okhotsk Sea and also in the western Russian Arctic.

These tankers include a large parallel midbody and a hull form that is not especially suitable for ice breaking. A hull rupture of these tankers in compressive ice would lead to catastrophic consequences in the Baltic. Further, the Baltic icebreaking system including the ice services are now responding to the increased tanker traffic to and from the Russian terminals in the eastern Baltic.

Similar change is likely to occur in the Okhotsk Sea, Russian western Arctic and possibly also in the White Sea. In developing ice service products applicable in these new sea areas, the present project contributes towards topics safety of ice navigation. Finally, it has been the observation of the Finnish and Swedish icebreaker services that the crews of the ice strengthened vessels do not have the necessary experience for winter navigation.

The Baltic Icebreaker Management (BIM, see www.baltice.org) is making every effort to increase the awareness for winter operations and ice conditions also awareness about the ice service products. A timely, easily comprehended, standardized and homogenized operational advice and ice navigation in a form of ice charts and ice forecasts will reduce the risk of human error in interpreting ice conditions and selecting a route through ice. Project also aims to understand the effect of ship structures onto risk of compressive ice damages.

This knowledge will used–then to redesign some part of the structure so to achieve the best possible damage resistance with reduction in structural weight.

3.2.13 TRITON TRusted vessel Information from Trusted On-board iNstrumentation

EU 7th FWP (Seventh Framework Programme), Transport themes: Intelligent transport systems, Transport management, Water transport (sea & inland)

Duration: 01/12/2013 -30.11.2015

Obtaining accurate and reliable positon is key factor for ESABALT system users. Having information about position any future action may be elaborated. ESABALT could benefit from TRITON (TRITON, 2015) project results, which aims to provide to the on-board unit a trusted GNSS-based source of positioning and timing information, robust to some intentional jamming and spoofing attacks, supporting the purposes of a robust ship reporting system. It may be used to report vessel information to the coggiontrol organisms. Today’s maritime surveillance operations rely on ship reporting systems such as AIS (Automatic Identification System), LRIT (Long Range Identification and Tracking) and VMS (Vessel Monitoring System), whose reported data (such as vessel ID, accurate position and time, course over ground, speed over ground, heading, rate of turn, etc.) are typically not verified nor validated in any way.

Methods of verification or validation of information to be exchanged between actors shall be utilized in ESABALT system.

3.3 R&D ESABALT associated projects

3.3.1 ASSET-ROAD ASSET advanced safety and driver support in essential road transport

EU 7th FWP (Seventh Framework Programme).

Duration: 01.07.2008 - 31.12.2011

The ASSET concept (ASSET, 2015) comprises the following main aspects:

- To develop a new "System Theory of Traffic Safety"
- To deduce from the theory, practical measures needed for an integrated safety system
- To develop and integrate technologies & architectures including a "Holistic System Design"
- To integrate different important and useful applications and built test sites
- To investigate functions, performances and operations and optimize the systems for future use

The consideration of multiple interactions between aspects of traffic safety will allow focused improvements.

Project objective: As the European objectives of integration and economic growth are achieved, there is a corresponding vigorous growth in road traffic volumes. This results in congestion and increased numbers of road fatalities. The objective of the ASSET project is to reverse these negative effects by developing a number of promising technologies and integrating them into a new holistic approach to road safety. The holistic approach will be at system and practical level. Integrated architectures will be developed to facilitate the exchange of secure information between road, vehicle and driver.

There will be a particular focus on the Human Machine Interface developing supporting systems which pass on safety-critical information to the driver. Driver monitoring technologies such as track and trace will use computer vision to identify abnormal driver behaviour (speed, gap, load) and inform driver and authorities. - Improving drivers knowledge and behaviour - Increased automation and traffic control for safety/efficiency - Innovative measures for safe and sustainable infrastructure A number of technologies will be developed and integrated into the holistic system like a thermal imaging tool to detect dangerous heavy goods vehicles, a new weigh-in-motion sensor which can detect critical tyres as well as overloaded.

The main theme is the integration of different information from different sources into a comprehensive system and the communication of the relevant information to where they are needed. Several application areas will be developed with concrete deliverables such as a safety station, crisis and dangerous goods management and an infrastructure life cycle optimisation system. Systems will be tested at a number of sites in different parts of Europe and results disseminated through seminars, workshops and demonstrations.

For the ESABALT project the most interesting outputs are:

- Developed architectures of the ASSET system
- Developed technics and technologies to pass information to the human
- Integration of different information from different sources

According to architecture, number of potential users and amount of transferred information, the ASSET system is quite similar to ESABALT system. The developed solutions might be useful for information aggregation, integration and fusion.

3.3.2 EFFORTS Effective Operations in Ports (EFFORTS)

The European FP-6 DG Research Integrated Project
Duration: 2006-05-01 to 2009-10-31

The Project 'Effective Operations in Ports (EFFORTS)' (EFFORTS, 2015) aimed to improve the competitiveness of European port operations and the quality of the ports labour conditions and market, being a prominent one in coastal regions. Commencing 1 May 2006 and lasting for 42 months EFFORTS, research and development focussed on three scopes of application:

- **Navigation in Ports**: three work packages dealing with safe and efficient approach and berthing of vessels usually increasing size faster than port infrastructure can follow;
- **Ports and environment**: four work packages covering the most relevant environmental areas related to port operation;
- **Port organisation**: two work packages providing an architecture and process description all operations

Methodology: The horizontal work packages served to integrate the results from the vertical work packages to a holistic picture. A project of the size of an IP required stringent horizontal planning, monitoring and assessment to exploit project resources in an optimum way. The horizontal WPs also had an important service function to make the wide spectrum of knowledge aware and available to all WP-teams, to solve problems and clarify issues of common project interests centrally and organize internal and external support for problem solving.
It was the horizontal platform where integration took place and where results could be also put into context of relevant social and policy (EC) conditions and communities.

For ESABALT this project might be interesting as the solution for cooperation in management of system divided between different subjects (authorities) from different countries. Other interesting things are: the use of digital maps, monitoring of port operations and environment.

3.3.3 MASAS Information Exchanges (MASAS-X) Pilot Project

MASAS-X Pilot Project in support of the broader MASAS Development Initiative. In November 2011, the Defence R&D Canada – Centre for Security Science launched the MASAS-X Pilot Project in support of the broader MASAS Development Initiative.

Duration: 2011 - 2012

MASAS (MASAS-X, 2015) is a multi-stakeholder federally-led initiative that aims to develop and support capabilities that will enable the sharing of location-based situational awareness information and alerts between emergency management and response agencies using open standards and an open architecture. The MASAS initiative is led by the Defence R&D Canada – Centre for Security Science, in partnership with Public Safety Canada and Natural Resources Canada, and represents an impressive collaborative effort involving federal, provincial, territorial and municipal governments, non-governmental organizations and industry.

MASAS-X is focused on operationalizing the pan-Canadian operational, exercise and training information situational awareness information exchanges that link the many stakeholders. These core operational services are being managed through a centralized office to offer a stable, reliable, resilient, long-term shared situational awareness capability within the Canadian public safety (and critical infrastructure) community.

For the ESABALT project the most interesting elements are solutions connected with communication, especially system of emergency messages. Also interesting might be distributed system for information collecting and the aspect of usefulness of the project in natural environment preservation.

3.3.4 SAFIRE - Situational Awareness for Fire Fighters

University of California Project, Center for Emergency Response Technologies (CERT)

Duration: 01.10.2008 - 30.09.2009

Emergency responders in all roles must process information, make critical decisions, take appropriate actions, and communicate effectively with others around them in order to preserve the safety of firefighters. These activities must be accomplished under dynamic and dangerous conditions where time is of the essence, and rarely with complete situational awareness. When a high level of situational awareness is achieved, more informed decisions can be made, resulting in much more effective actions and better management of risks. The quality of situational awareness that exists throughout all levels of the emergency response hierarchy has a direct impact on the safety of individual firefighters.

Achieving situational awareness requires acquisition of knowledge of past events, an in-context understanding of present circumstances, and anticipation of future events. It also requires a high degree of communication and coordination up-and-down the chain of command, as well as between peers, whether the peers are individual firefighters, incident commanders, or cities within an operational area.

The key deliverable of SAFIRE system (SAFIRE, 2015) is Fire Incident Command Board (FICB) through which the user can establish and maintain situational awareness utilizing a wide range of sensor and data streams from the field as well as existing centralized information systems such as CAD and GIS. The FICB prototype that will be delivered as a result of the project will be specifically targeted towards the needs of an incident commander.

For the ESABALT system the most interesting things are:

- Methods of acquisition and integration of large amount of different kind of information
- Use of past events to anticipate future events
- Methods of information presentation to different users of the system to increase situational awareness.

3.3.5 SAIL Situation Awareness by Inference and Logic

NICTA

NICTA Project, Australia.

Duration: 01.07.2007 – 30.06.2008.

NICTA (NICTA, 2015) is Australia's Information Communications Technology (ICT) Research Centre of Excellence and the nation's largest organisation dedicated to ICT research. NICTA's primary goal is to pursue high-impact research excellence and, through application of this research, to create national benefit and wealth for Australia. We aim to be one of the world's top ICT R&D centres

Situation awareness is concerned with perceiving elements of an environment in time and space, comprehending their meaning and projecting their status in the near future. Good situation awareness is very important for managing dynamic real-time situations like military scenarios, natural or man-made emergencies and transport situations like air traffic control.

NICTA's SAIL (Situation Awareness by Inference and Logic) Project helps decision makers have better situation awareness by providing a system that uses formal logic to answer questions about the objects and events of a situation, and issue alerts when it recognizes factors of interest emerging in the situation.

The SAIL Technology uses a novel approach that includes formal logics and ontologies to represent the situation, and automated reasoning to infer logical consequences. The logical machinery acts on input data from sensors and other sources to build an overall representation of the situation in logical form. This representation is constructed in real-time, and can be interrogated for question answering and alert generation via the use of controlled natural language that translates English to and from the logical form used by the system.

The approach is very modular and may be applied in any domain where situation awareness is needed.

The aim of the project is to build a system for decision makers which improve a situational awareness, what means perceiving the elements of the surrounding environment at a specific time and space, understanding their meaning and how they will change in the near future. Situational awareness should be seen as a detailed knowledge about this what happens around us and what might be expected. Disturbance of situational awareness is a key factor to cause human errors which leads to aviation accidents, maritime disasters or mistakes in medicine invasive (surgery, anesthesiology).

The system proposed in the project consists in automation of reasoning based on input from sensors and other measuring devices, which provides a representation of the situation in a logical form. The platform is constructed in real time and provides answer, warnings, by using a natural language, in this case English.

Designed approach is modular and can be used in any area where the situational awareness is needed. The output of the project can therefore be used to increase the situational awareness for the purpose of improving maritime safety in the Baltic Sea.

The proposed technology might be interesting as a inspiration for reasoning system which could be implemented in future development of ESABALT project.

3.3.6 MarCom – broadband at sea (Maritime Communication)

MarCom broadband at sea

MARINTEC Project.

Duration: 2007-2010

Main objectives of MarCom (MARCOM, 2015) are to investigate the main user needs and Communications Technologies requirements to accommodate those needs within maritime community. The Project will carry out several pilots to demonstrate the usability of terrestrial wireless Technologies In combination with, and in some areas instead of satellite communications (SatCom). The major benefits to the maritime users are expected to be reduced costs, increased bandwidth, quality-of-service (QoS) and improved Communications security and versatility.

The MarCom project, realized by the Norwegian Marine Technology Research Institute (MARINTEK), performs research and development for companies in the field of marine technology.

Main objectives of the Project are to investigate the main user needs and Communications Technologies requirements to accommodate those Leeds within maritime community. Within the design research in some areas there is trying to replace the satellite communications (SATCOM) by terrestrial wireless technology. This leads to lower the cost, increase the bandwidth and the quality-of-service (QoS) and improve the security and flexibility of communication, what is the main benefit for the users of maritime transport. The MarCom investigations have revealed the bandwidth needs for a set of application groups, and identified the data integrity requirements for each group. Therefore the ESABALT project could benefit from MARINTEC project outputs.

3.3.7 TESSA – Development of technologies for the "Situational Sea Awareness"

Project funded by Programma Operativo Nazionale "Ricerca e Competitività" 2007-2013

Duration: 01.01.2012 to 31.05.2015

The general objective of this project (TESSA, 2015) is to improve and consolidate the products and the operational oceanography service in Southern Italy and to integrate this service with technological platforms of dissemination of information for the 'Situational Sea

Project realized by The Euro-Mediterranean Centre on Climate Change. It is a non-profit research institution established in 2005, with the financial support of the Italian Ministry of Education, University and Research. CMCC manages and promotes scientific and applied activities in the field of international climate change research. The main goal of the project is the improvement and consolidation of products and services of operational oceanography in southern Italy under the technology platform. The main project activities include:

- operational modelling with high resolution. Improvement of geo-space-temporal data for the Southern Italy Seas;
- operational oceanography centers – Improvement of geo-space-temporal data for the Southern Italy Seas;
- Data Repositories – Technological platforms of "Situational Sea Awareness" – SSA;
- Intelligent Decisions Support Systems for complex dynamical environments. Technological platforms of "Situational Sea Awareness" – SSA;
- tests and demonstration of services and products – technological platforms of "Situational Sea Awareness" – SSA.

4 Navigation technologies

One important technological area in the ESABALT concept is navigation technologies. This section will briefly review the state-of-the-art in this area. There is some overlap with Section 3, as navigation technologies play a key role in maritime safety. This section, however, will go into greater detail concerning the technologies. Then, certain prospective technologies are addressed.

4.1 Existing technologies

The technologies described in this section are mature and already in use in modern vessels.

4.1.1 Electronic Chart Technology

This section describes several different types of electronic chart technology used on vessels.

ECDIS

As described in Section 3.1.1, ECDIS combines digital navigation charts with various navigation technologies available in modern vessels. ECDIS is being mandated by law and must be retrofitted on existing ships, depending on the vessel size, by approximately July 2018 (certain exceptions apply); it is required in all new ships starting from July 2014 (Jeppesen).

Electronic Navigational Charts

The term “Electronic Navigational Chart” (ENC) refers to nautical charts that have been certified as conformant to the standards defined in IHO Special Publication S-57; ENCs are created by national hydrographic offices. The ECDIS performance standard as stated by the IMO requires the use of official ENC data.

Other digital nautical charts

Unofficial nautical charts exist as well, e.g., OpenSeaMap (OpenSeaMap 2015) where the depth readings have been obtained by means of crowdsourcing (WasserTiefe). Obviously, they cannot (and are not even designed to) replace official ENCs for ECDIS but they could be useful as complementary information in cases where ENC data seem to be lacking. However, the integrity of the (unofficial) chart data must be ensured by some means.

4.1.2 Satellite-based Navigation

Global Navigation Satellite Systems (GNSS), and in particular the U.S. Global Positioning System (GPS), are probably the most popular means of positioning in the world. When operating without disruptions, a GNSS receiver can resolve its position with accuracy in the order of 10 meters and velocity in the order of 1 m/s accuracy. However, the satellite signals are so weak in power that they are susceptible to interference. Therefore, GNSS receivers need efficient algorithms to detect if the position solution is not trustworthy; furthermore, alternative positioning means must be available under such conditions.

4.1.3 Radar

Radar can detect objects such as vessels and estimate their distance and speed. When combined with an ARPA (automatic radar plotting aid) system, other supportive information such as the effect of different maneuvers (course or speed change) to, e.g., avoid a collision, can be shown on the display.

4.1.4 Azimuth Reference

The SOLAS (Safety of Life at Sea) Convention mandates that all vessels must have an appropriately adjusted compass or other non-electronic azimuth reference. In addition, vessels larger than 500 gross tons need to have a gyrocompass or other non-magnetic azimuth sensor. These two types of systems are complementary in nature: magnetic compasses are subject to short-term errors due to deformations in the local magnetic field whereas gyrocompasses tend to slowly drift as time passes.

Magnetic fluxgate compasses provide their output directly in electronic form, thus being easy to couple with an ECDIS, but do not satisfy the requirement of independence of external power. Therefore, a traditional magnetic compass is still needed as a backup.

As opposed to magnetic compasses, gyrocompasses are expensive to manufacture; furthermore, mechanical gyrocompasses have a limited lifetime and require maintenance. The latter two issues could be avoided by using optical sensors such as ring laser gyroscopes (RLG) which contain no moving parts, but RLGs are expensive as well. Also note that gyrocompasses are always electronic.

4.1.5 Speed log

Measuring the travel speed of the vessel makes it possible, when combined with an azimuth reference, to estimate the position of the vessel by means of dead reckoning. Modern speed logs are based on measurements from an impeller attached to the ship hull, ultrasound, or the Doppler effect. Even GNSS measurements also make it possible to precisely estimate the speed, but suffer from limited availability.

4.1.6 Echo Sounder

Measuring the sea depth using sonar obviously does not directly yield position information. However, the measured depth information can be compared with nautical charts, but the density of the depth grid seems to vary locally, being most dense in shallow seaport areas (OpenSeaMap 2015).

4.1.7 Automatic Identification System

Although AIS can be used with ECDIS, AIS is not analyzed here; AIS systems are addressed in detail in Task 3.5 (Section 7 of this document).

4.2 Emerging Technologies

The technologies analyzed in this section are mostly either not yet mature or only build on the information already available from ECDIS.

4.2.1 Multi-GNSS

A promising method of improving the reliability of GNSS positioning is to use multiple satellite systems, i.e., not only GPS but also GLONASS, BeiDou and Galileo. The advantages of multi-GNSS are at least twofold. First, the sheer number of available satellites and signals increases significantly, which decreases the probability of a positioning failure due to an inadequate number of satellites in view. Second, using multiple constellations mitigates the risk of control segment errors because each system has its own control segment; therefore, a system error such as (Gibbons 2015) can be detected and isolated based on the other GNSSs.

Currently, two GNSSs (GPS and GLONASS) are in full operational capability. The deployment of Galileo and BeiDou is underway, but the schedules are tentative, especially for Galileo; it will take years until they reach full operational capability, but a limited number of satellites are already available for the systems.

4.2.2 EGNOS

The European Geostationary Navigation Overlay Service (EGNOS) is an exception in this section in the sense that can be regarded as a mature technology and assists GNSS directly without dependence on ECDIS. As a satellite-based augmentation system, EGNOS can provide GNSS users with extended integrity and position error correction data.

When considering the Baltic Sea, EGNOS has the problem that its geostationary satellites can only be seen at fairly low elevation angles at high latitudes; fortunately, in maritime environments, the sky view tends to be unobstructed, and at least three EGNOS satellites are above 10° elevation in almost the entire Baltic Sea, with one constantly exceeding 15° in elevation (Fairbanks et al 2000).

4.2.3 Low-Cost Inertial Sensors

Inertial sensors (i.e., accelerometers and gyroscopes) are self-contained motion sensors whose measurements can be integrated in order to perform autonomous dead reckoning. The sensors are insensitive to environmental disturbances but their measurement errors tend to accumulate during the integration of the measurements. For this reason, expensive high-quality inertial sensors are required for autonomous long-term dead reckoning.

However, low-cost microelectromechanical (MEMS) inertial sensors are constantly improving in performance. Therefore, they could be used for short-term navigation during a temporary unavailability of other systems, such as a GNSS outage; the question is, how long a gap they can bridge yet maintaining the required position accuracy.

It is noteworthy that inertial sensors measure movement with respect to a non-accelerating and non-rotating inertial frame, i.e., not with respect to the sea water.

4.2.4 Routing and Collision Avoidance

As ECDIS combines virtually all the available situational awareness information (charts, navigation, AIS, etc.), it would be natural to fuse these sources on information together. For instance, (Banachowicz 2013) describes an elementary approach to fusing navigation coordinates with nautical chart features.

Automatic collision avoidance based on radar and AIS observations is another application of data fusion. According to the test results reported in (Heymann 2013), targets detected by AIS and ARPA do not always match; for instance, the average ARPA availability for a given AIS-detected object was observed to be only 56 %. However, it was acknowledged that there were time synchronization errors.

5 Earth Observation technologies

In the past decades, huge investments have been made into the Earth Observation (EO) satellite programmes globally. Probably the most famous examples are the Landsat programme by the United States, European ERS and Envisat satellites, and the current European Copernicus programme (former GMES, Global Monitoring for Environment and Security). It is clear that EO technologies offer valuable wide-area information, which cannot be measured and monitored otherwise. One of the most important application area of EO data is mapping and monitoring of the maritime environment. The use of EO data in maritime applications has been widely researched and there already exists operational services providing, for example, near real-time ice sheet maps, oil spill detection and seafaring vessel monitoring.

There are several EO satellites and sensor technologies available for maritime applications. is the usability of EO data depends on the application requirements and the user needs, such as EO data costs and spatial and temporal resolution of the satellite sensor. This chapter evaluates current and future EO technologies for the ESABALT system. For the ESABALT system, the most significant maritime applications operationally utilizing EO data are oil spill and seafaring vessel detection, ice sheet mapping and marine weather forecasting, such as water temperature, wind and wave forecast.

5.1 Earth Observation Technologies for marine environment monitoring

An Earth observation system for monitoring maritime environment typically includes a variety of remote sensing (RS) instruments, such as space-based (i.e. satellites), airborne and terrestrial and *in-situ* instruments, as well as RS data analysis methods. RS instruments are divided to passive and active instruments. Passive RS instruments measure the radiation naturally reflected or emitted from the object of study, whereas active sensors are themselves emitting the radiation they are measuring. Examples of passive sensors are imagers working in visible and infra-red region measuring the reflected sunlight from the sea surface. Active RS instruments include for example LiDARs and radars, such as Synthetic Aperture Radar (SAR). (Kramer, 2002; Miller et al., 2007)

RS technologies are also categorized by the wavelength region the instrument is measuring. Marine environment is monitored by instruments measuring radiation at ultra-violet, visible, near-, middle- and thermal infra-red and in microwave region. The data properties, such as spatial, spectral and temporal resolution and data coverage, vary much between the data produced by different sensors. In addition, some sensors types are better for different applications. Thus, the best data products are acquired by combining the data from different sensors by modeling and data assimilation.

The next sections describe the RS technologies that are operationally used in maritime environment monitoring. A brief description of each instrument type and its applications in maritime monitoring is provided. Table 1-5 presents the currently operational and future satellite missions using specific type of RS technology. More detailed description how the different RS technologies are used in specific maritime applications will be given in Section 5.2.

5.1.1 Passive Microwave

The microwave region between 0.1-100 cm is widely used in marine environment monitoring. Passive microwave imagers are based on detecting the naturally emitting microwave radiation from the Earth surface both in land and water areas. Passive microwave imagers usually measure microwave radiation in several channels. Atmosphere and clouds are transparent to microwave radiation and thus enabling all-weather measurement capability, except during heavy rain. Microwave radiation is emitted from the sea also without reflected solar radiation and thus microwave sensors are able to receive data also at nights. (Martin, 2013)

Passive microwave sensors can be used to measure, for example:

- sea surface winds
- sea surface temperature
- sea ice
- snow
- sea salinity

Passive microwave sensors are mainly space-based sensors, an example being the SMOS satellite by ESA (SMOS, 2015). Their major disadvantage is coarse spatial resolution which is approximately 5-100 km. Better spatial resolution would require very large antennas which are not sensible for satellite or airborne systems.

Table 1 Current and future passive microwave satellite missions

Satellite	Instrument	Agency	Bands	Swath	Spatial resolution	Repeat cycle (days)	Launch date
FY-3C, FY-3D	MWRI	NRSCC, NSMC-CMA (China)	12 channels: 10.65-150 GHz	1400 km	7.5-85 km	-	2013 (3C) 2015 (3D)
SMOS	MIRAS	ESA	1.41 GHz (L-band)	1050 km	33-50 km	23	2009
SAC-D / AQUARIUS	Aquarius L-Band radiometer	CONAE (Argentina), NASA (US)	1.41 GHz (L-band)	300 km	100 km	7	2011
GCOM-W1	AMSR-2	JAXA (Japan)	7 channels: 6.9-89 GHz	1450 km	5 – 50 km	16	2012

5.1.2 SAR (Synthetic Aperture Radar)

SAR imaging technology is an active RS technology using microwave radiation. SAR technology utilizes the motion of the antenna, in satellite or airplane, to create a synthetic aperture (i.e. very long antenna) enabling high spatial resolution imaging. SAR satellites produce two-dimensional images where image brightness is a reflection of the microwave backscattering properties of the surface (Brekke and Solberg, 2005). The major benefit of this technique is its capability to acquire EO data through clouds and independently of solar illumination.

Typical resolution (i.e. minimum separation of two objects) of data produced by SAR satellites is from about one meter to 150 m and image swath width from 100-500 km depending on the used imaging mode. In maritime applications wide swath with lower resolution are typically used for their ability to monitor wider areas than high resolution SAR data. Examples of SAR imaging modes can be seen in Section 5.3 where Sentinel-1 imaging modes are briefly described.

SAR satellites can utilize polarimetry of electromagnetic (EM) radiation to produce additional information of measured surfaces. SAR pulses are usually either vertically or horizontally polarized. By transmitting and receiving different polarizations, information about surface geometry and orientation can be acquired. For example, vertical structures, such as high buildings, have brighter backscattering at vertical polarization and flat surfaces have brighter backscatter at horizontal polarization. Polarimetric information has been utilized in maritime application. For example, VH cross-polarization, where vertically polarized pulses are transmitted and horizontally pulses received, has been shown to work better for ship detection than VV (vertically transmitted and vertically received) (Martin, 2013). The use of polaritmetric SAR has also been studied in oil slick detection and iceberg research (Martin, 2013)

Applications of SAR in maritime monitoring include:

- Sea ice and snow monitoring
- Oil spill detection
- Vessel detection
- Near-surface winds estimation
- Algal bloom estimation

SLAR (Side-Looking Airborne Radar) is airborne or satellite-based imaging radar pointing typically perpendicular to the direction of flight. It uses a large real aperture radar (RAR) which uses a long antenna to achieve spatial resolution (Fingas and Brown, 2014). SLAR has previously dominated airborne radar imaging due to lower price. However, due to the development of SAR technology, the use of SLAR has decreased. . Applications of SLAR are the same as with SAR.

Table 2 Current and future satellite SAR missions

Satellite	Instrument	Agency	Bands	Swath	Spatial resolution	Repeat cycle (days)	Launch date
RADARSAT 2	C-Band SAR	CSA (Canada)	C (5.405 GHZ)	1400 km	7.5-85 km	24	2007
TerraSAR-X TanDEM-X	X-Band SAR	DLR (Germany)	X (9.65 GHz)	5-100 km	1-16 m	11	2007 & 2010
COSMO-SkyMed Constellation (4	SAR 2000	ASI (Italy)	X (9.6 GHz)	10-200 km	1-100 m	7	2007-2010

satellites)							
Sentinel 1A & 1B	C-Band SAR	ESA	C (5.405 GHz)	80-400 km	9-50 m	12 repeat cycle	2014 (1A), 2015 (1B)
ALOS-2	PALSAR-2	JAXA (Japan)	L (1.27 GHz)	25-490 km	1-100 m	14	2014

5.1.3 Altimeters

Altimeters are nadir looking radars or lidars that measure the range between the satellite and sea surface. Altimeters transmit short pulses of microwave radiation (mostly at C or Ku band) vertically downward to the sea surface and measure the reflected signal. Measuring the time-of-flight between the transmitted and received pulse the range between the satellite and sea surface can be acquired to an accuracy of 2-3 cm. When the satellite orbit and the local geoid are known, changes in the sea level and wave heights can be monitored. The strength of the measured reflected signal from the sea surface provides information about the sea surface characteristics, such as sea surface roughness and incidence angle, which can be used to estimate sea surface winds and wave direction. (Martin, 2013)

Marine environment applications of altimeters are:

- Sea-surface height
- Ocean surface wind speed
- Wave height
- Sea ice

Table 3 Current and future satellite altimeter missions

Satellite	Instrument	Agency	Bands	Swath / Spatial resolution	Height estimation accuracy	Repeat cycle (days)	Launch date
OSTM/ JASON-2	Poseidon-3	NASA (US) & CNES (France)	C & Ku (5.3 & 13.6 GHz)	300 km between tracks at equator 6 km along track	Sea level: 3.9 cm Significant wave height: 0.5 m Wind speed: 2 m/s	10	2008
CryoSat-2	SIRAL	ESA	Ku (13.575 GHz)	Footprint: 15 km, Range resolution: 45 cm, Along-track: 250 m	Arctic sea-ice: 1.6 cm/year for 300x300 km cells, Land ice (small scale): 3.3 cm/year for 100 x 100 km cells, Land ice (large scale): 0.17 cm/year for Antarctica size area	369 days with 30 day sub-cycle	2010

HY-2A, 2B, 2C, “2D	Alt	NSOAS & CAST (China)	Ku & C (5.3 & 13.6 GHz)	16 km	< 4cm	14	2011 (2A), 2015 (2C), 2016 (2B), 2019 (2D)
SARAL	AltiKa	CNES (France) & ISRO (India)	35.75 GHz (Ka-band)	75 km between tracks at equator Footprint: 8 km Along-track: 2 km	3 -40 mm	35	2012
JASON-3	Poseidon-3B	NASA (US) & CNES (France)	C & Ku (5.3 & 13.6 GHz)	300 km between tracks at equator / 6 km along track	Sea level: 3.4 cm Significant wave height: 0.4 m Wind speed: 1.5 m/s	10	~2015
Sentinel-3	SRAL	ESA	C & Ku (5.3 & 13.6 GHz)	SAR along track resolution ≈300 m SAR across track resolution ≈1,64 km LRM along track resolution ≈1,6 km LRM across track resolution ≈1,6 km 18.2 km (Ku), 48.4 km (C)	3 cm	27 -4 2days	~2015
ICESat-2 (LiDAR)	ATLAS	NASA	1064 nm	Along-track 70 cm	-	183 days	~2015

5.1.4 Scatterometers

Scatterometers are radars designed to measure wind speed and direction at the sea surface. Scatterometers send short radar pulses to the sea surface at variety of incidence angles and detect changes in the backscattered radar pulse echo. This gives information about the sea surface roughness and incidence angle which can be used to estimate the speed and direction of waves and winds. (Martin, 2013)

Marine environment applications of scatterometers are:

- Wind speed and heading (10 m above ocean surface)
- Rain

- Sea ice; concentration & extent

Table 4 Current and future satellite scatterometer missions

Satellite	Instrument	Agency	Bands	Swath	Spatial resolution	Repeat cycle (days)	Launch date
METOP-A	ASCAT-A	ESA	C (5.3 GHz)	2 x 500 km	25-50 km	29	2006
SAC-D / Aquarius	Aquarius L-Band Scatterometer	NASA	L (1.2 GHz)	300 km	100 km	7	2011
HY-2A	SCAT (Scatterometer)	NSOAS & CAST (China)	Ku (13.256 GHz)	1300 km	50 km	14	2011
METOP-B	ASCAT-B	ESA	C (5.3 GHz	2 x 500 km	25 – 50 km	29	2012
CFOSAT	SCAT (Wind Scatterometer)	CNSA (China)/ CNES (France)	Ku (13.256 GHz	1000 km	50 km	-	~2018
METOP-C	ASCAT-C	ESA	C (5.3 GHz	2 x 500 km	25 – 50 km	29	~2016

5.1.5 Optical remote sensing (400-2500 nm)

Ultraviolet (UV)

Due to strong absorption and scattering of ultraviolet (UV) radiation (100-400 nm) in the atmosphere, the UV spectral region is mainly utilized in airborne and *in situ* instruments. One of the major maritime applications is oil spill detection. Oil has higher reflectance at UV than clear water (Fingas and Brown, 2014), which can be utilized to determine the relative thickness and area of oil slicks. UV sensors are operationally used in airborne oil spill RS (Gruner et al., 1991). UV spectral region is also used in ocean color RS, especially to estimate dissolved organic matter (DOM) concentrations in water bodies.

Applications of UV sensors are:

- Oil spills
- Ocean color (*in situ*)

Visible & near infra-red (VIS & NIR)

Sensors measuring the visible (VIS) and near infra-red (NIR) part of the electromagnetic spectrum (VIS: 400-780 nm, NIR: 780-1000) concentrate on measuring the optically active water constituents, such as the oceanic chlorophyll *a,* which is a pigment associated to photosynthetic activity in ocean plants. Visible radiation is the only part of the electromagnetic spectrum that can properly penetrate into water columns. Thus it is used in bathymetry and to estimate substance concentration below the sea surface. Major drawback of passive sensors measuring the VIS-NIR spectral region is the requirement of cloud-free weather to receive data from the sea surface. (Martin, 2013; Miller et al., 2007)

The main application areas in measuring visible spectral region are:

- Ocean color
- Phytoplankton & algae
- Biogeochemistry

Infra-red &, Thermal infra-red (IR & TIR)

At the infra-red (IR) region between 1000 nm – 1 mm, the most used spectral region for ocean RS is the thermal infra-red region (TIR). TIR is widely used for monitoring sea surface temperature (SST), especially at the long-wave IR (LWIR; 10-12.5 µm) and the short-wave IR (SWIR; 3.7-4.2 µm) (Miller et al., 2007). Cloudiness has an effect on the IR radiation, and thus reliable ocean monitoring in the IR requires some degree of cloud-free conditions. In addition, part of radiation at these wavelengths is absorbed by the atmosphere, which requires atmospheric correction methods. TIR radiation is emitted from the sea also without solar radiation which enables STT monitoring also at night. TIR is also used to detect oil spills as oil absorbs more radiation and thus emits more thermal radiation (Leifer et al., 2012).

In marine environment monitoring, thermal IR radiation is used for application, such as:

- Snow and ice detection
- Sea surface temperature (SST) estimation
- Oil spill detection

Table 5 Current and future optical satellite missions contributing to ocean remote sensing

Satellite	Instrument	Agency	Bands	Swath	Spatial resolution	Repeat cycle (days)	Launch date
TERRA & AGUA	MODIS	NASA	VIS - TIR: 36 bands in range 0.4 - 14.4 µm	2330 km	250 / 1000 m	16	1999 (Terra) & 2002 (Agua)
FY-3C, FY-3D	VIRR	NRSCC, NSMC-CMA (China)	VIS-TIR: 10 channels over 0.43 - 10.5 µm	2800 km	1100m	-	2013 (3C) 2015 (3D)
METOP & NOAA Satellites (8 satellites)	AVHRR-3	NASA (US), NOAA (US), ESA	VIS-FIR: 0.4 µm - 0.1 cm	3000 km	1100m	29	1998-2018
SAC-D / Aquarius	HSC	CONAE (Argentina)	VIS-NIR: 0.40 µm - 1.3 µm	1600 km	200 - 300 m	7	2011
Suomi-NPP	VIIRS	NASA / NOAA	VIS - TIR: 0.4 - 12.5 µm (22	3000 km	400 m - 1.6 km	16	2011

			channels)				
Sentinel-3 (A, B, C)	OLCI SLSTR	ESA	21 bands in VNIR/SWIR 9 bands in VNIR/SWIR/TIR	1270 km 1675 km	300 m 500 m - 1 km	27	2015-2020
Landsat-7	ETM+	NASA	VIS - TIR: 8 bands: 0.45 - 12.5 µm	185 km	Pan: 15 m, VIS - SWIR: 30 m	16	1999
Landsat-8	OLI TIRS	NASA	VIS - SWIR: 9 bands: 0.43 - 2.3 µm TIR 10.5 µm and 12 µm	185 km 185 km	100 m PAN: 15 m, VIS - SWIR: 30 m, TIR: 60 m	16	2013
RapidEye1	MSI	DLR (Germany)	4xVIS & 1xNIR	78 km	6.5 m	1	2008
SAC-E (A & B)	UV-VIS	CONAE (France)	11 bands between 380 – 865 nm	1350 km	200-800m	4	~2018

5.1.6 LiDARs / Lasers

Lidars are active RS instruments that can operate at spectral region ranging from UV to IR regions. They are based on measuring the time-of-flight of laser pulses between the instrument and measurement target (i.e. the range to the target). In marine environment monitoring, lidars are mainly used in airborne platforms, but there also exists satellites using lidar instruments, such as NASA's ICESat GLAS (the Geoscience Laser Altimeter System), which has also been utilized in sea ice thickness measurements (Zwally et al., 2002). The main lidar instruments used in marine environment RS are laser altimeters, bathymetric lidars and laser fluorosensors.

Laser altimetry

Laser altimeters work similar to radar altimeters, but they use IR laser pulses instead of microwave pulses. There exist several space- and airborne laser altimeters. Laser altimeters can produce higher resolution compared to microwave altimeters, but especially spaceborne lidars are obscured by clouds.

Laser altimeters are used to estimate Marine environment parameters, such as:

- Sea-surface height
- Ocean surface wind speed
- Wave height
- Sea ice

Lidar bathymetry

Lidar bathymetry is used for measuring shallow water depths. Usually lidar bathymetry uses two laser sources: the first one with green wavelength which can penetrate water column (up to 50 m depending on water clarity) and the second at IR which is reflected from the sea surface.

Laser fluorosensors

Laser fluorosensors use the phenomenon where aromatic compounds in petroleum oils absorb UV radiation and become electronically excited. This excitation is rapidly removed through the process of fluorescence emission, primarily at the visible region of the spectrum (Fingas and Brown, 2014). Laser fluorosensors are used for example in oil spill detection utilizing UV laser in 308-355 nm region.

5.1.7 Airborne, shipborne and *in situ* remote sensing technologies

Airborne sensors

Airborne platforms can in principle carry any kind of sensor mentioned above. Common airborne platforms are, for example, UAVs (Unmanned Aerial Vehicle), airships, helicopters and standard aircrafts.

Characteristics of airborne RS data compared to satellite instruments:

- Airborne sensors are closer to ocean, and thus they may have better spatial resolution, but the coverage of the monitored area is much smaller, especially in case of UAVs.
- Airborne sensors can fly under the clouds which enables the use of optical sensors during cloudiness.
- Obtaining wide area coverage using airborne RS is typically more expensive than satellite EO data (Tsui et al., 2013).

Shipborne sensors

Shipborne sensors, such as oil and ice radar have been described in Section 3. Review of maritime safety approaches.In situ RS technologies

In situ RS technologies provide data locally and wide *in situ* sensor platform network is produced to provide data for wider areas. Mostly *in situ* data is used in combination with satellite data in data assimilation to enhance and specify the estimate or forecast produced using the assimilation model.

Here are listed some *in situ* technologies used in monitoring marine environment (Miller et al., 2007):

- Stationary vertical profilers
- Flow-through systems
- Towed vehicles
- Moored Platforms
- Profiling floats
- Automated Underwater Vehicles (AUVs)
    - Self-propelled vehicles

    - Gliders
- Divers (Carrying for example optical devices)

5.2 Maritime applications utilizing EO data

Main maritime applications that are significant for ESABALT and where EO technologies have been operationally used are oil spill and seafaring vessel detection, ice sheet mapping and marine weather forecasting, such as sea surface temperature, wind and wave direction and speed. The use of EO technologies in these applications is briefly described in the following sections.

Oil Spill Detection using EO technologies

Various RS techniques have been utilized in oil spill detection (Fingas and Brown, 2014; Leifer et al., 2012), but the use of satellite based SAR has become the most dominating EO technology in oil spill detection due to its capability to produce wide-area information both day and night and through clouds and fog (Fingas and Brown, 2014).

SAR based oil spill detection is based on detecting dark areas in SAR imagery caused by dampened Bragg scattering induced by oil film on the sea surface (Ferraro et al., 2010). In addition to oil spills, microwave backscattering from sea surface can also be dampened due to natural phenomena. Thus, the main disadvantage of satellite based SAR is the relatively high tendency to false targets, induced for example by low wind areas, rain cells, algae blooms etc. (Fingas and Brown, 2014). Consequently, additional procedures, such as airborne surveillance, are usually required to verify the oil spill and to identify the polluter (Salberg, 2013). Currently, most operational oil spill detection services rely on manual detection where human operators are trained to analyze images for detecting oil spills. However, much research has been conducted to implement automatic or semi-automatic oil spill detection methods.

In addition to SAR technology, oil spill detection has also been performed and researched using various other RS technologies, such as:

- optical RS (VIS-thermal IR, ultraviolet)
- passive microwave RS
- ship- and airborne radar
- laser fluorosensors

Review of these technologies in oil spill detection has been conducted for example by Fingas & Brown (2014) and Leifer et al. (2012).

Oil spill detection using SAR technology is already implemented operationally used in services, such as EMSA's CleanSeaNet (CSN). In addition, Copernicus project SeaU studied the use of RS satellites, especially Sentinel-1 satellite, in oil spill and polluter detection.

Ice mapping using EO technologies

Mapping the sea ice thickness, extent and drift has a special importance for marine navigation, but it also has a major role in studying Earth's environment. Due to high albedo (reflectivity) of sea ice, it has a strong effect to the total solar budget of Earth. In addition, sea ice maintains the dynamic salinity equilibrium of the oceans (Teleti and Luis, 2013). Sea ice mapping using RS technologies has been studied extensively and operational sea ices services has been established.

For navigational purposes, a major emphasis in sea ice mapping is on real-time or near-real-time information. Thus, sea ice monitoring using spaceborn RS is mainly based on using passive microwave and SAR instruments which are not drastically affected by cloudiness or dependent on solar illumination. A major drawback of passive microwave sensors is their coarse spatial resolution. Consequently, SAR data is more suitable for navigational applications where better spatial resolution is needed. However, swath widths are smaller with SAR sensors than with passive sensors, and thus limit the coverage and temporal resolution of SAR imagery. Data from *in situ* measurements, such as ice buoys, is also greatly used in sea ice mapping to compensate the data acquisition gaps of satellite RS. (Askne and Dierking, 2008; Sandven, 2008)

In SAR imagery the brightness of ice surface backscattering intensity is influenced by the ice surface characteristics (roughness, snow and melt water coverage), volume structure (shape and orientation of air bubbles and brine inclusions; density, wetness and grain size) and dielectric properties (salinity and temperature). The ability of SAR to image different sea ice properties depend on the frequency, polarization and incidence angle of the SAR pulses. For example, the intensity of volume scattering depends on the penetration depth which increases with increasing radar wavelength. (Askne and Dierking, 2008; Martin, 2013)

An important aspect for sea ice monitoring is also the ability to measure the drift of ice. Various satellite based systems have been used to estimate ice drift, such as SAR, passive microwave, scatterometers and altimeters. SAR has been shown to be beneficial when detailed ice drift information is needed from smaller region. However, the estimation is based on tracking the sea ice drift from consecutive images which means that imagery with good temporal sampling (one to two days) is required. (Askne and Dierking, 2008; Sandven, 2008)

SAR sensors have been shown to be beneficial in sea ice monitoring for navigational purposes. However, other RS methods are also used in sea ice monitoring. Best results are achieved if different methods are used in synergy, the most common method in operational services being the use of data from SAR satellites and ice buoys in the same ice forecast model.

Vessel detection using EO technologies

Vessel detection and identification is an important task for maritime security and environmental protection. Vessel detection in the European seas is needed mainly in fisheries and pollution control and maritime border security. The use of RS in detecting seafaring vessels has been widely studied and it has shown to be beneficial in this task, but there exists some notable limitations. First, satellites orbits have certain repeat and revisit frequencies, which may lower the usability of satellite EO data in near-real-time vessel detection.

SAR and optical RS satellites have shown to have adequate spatial resolution to detect seafaring vessels. When high resolution optical imaging is possible, it can produce information which can even be used to identify and classify individual ships. However, such high resolution optical images as that can only image small areas at a time. In addition, optical imaging is limited by clouds and fogginess and impossible during night. Consequently, SAR offers better RS technology for ship detection. (Greidanus, 2008)

A major benefit using radar technology, such as SAR, is that ships over oceans are very bright compared to the dark sea water. The backscattering brightness from ship is affected by the ships orientation relative to the satellite and the polarization of the radar pulse. The ability of SAR to detect ships is hindered by strong winds, heavy rain and rough sea state that cause sea clutter. In addition, strong winds cause the ships to pitch and roll which blurs the ship in SAR image and the location of the ship in SAR image can be distorted in azimuth direction if the ship is moving. However, this can also be used to detect the direction and speed of the ships movement. (Greidanus, 2008)

Surface winds and waves

Estimating and forecasting ocean surface winds and waves is an important task for maritime safety. Surface winds affect the size of waves and strength of ocean currents. Ocean waves and surface wind direction and speed has been estimated using microwave RS technologies such as SAR, passive microwave imaging, scatterometers and altimeters. Methods are based on detecting the incidence angle changes in sea surface and gravity-capillary waves which can be detected by wind induced strikes and changes in sea surface roughness. Information about ocean currents, wave and winds can be used to improve maritime safety but also for ship route and fuel consumption optimization. (Martin, 2013)

Sea surface height (SSH)

Sea surface height measurements are needed to determine ocean circulation and monitoring seasonal and long-term variations in sea level. Sea level height is mainly estimated using altimeters by measuring the range between the sensor and the sea surface and subtracting the height of the local geoid. (Martin, 2013)

Ocean color & water quality

Ocean color and quality information is mainly measured using optical RS in the VIS and NIR region and laser fluorosensors. The sensors work at a wavelength range which is the only part of EM spectrum that appreciably penetrates into the water column. Penetration can be up to 30 m depending on weather conditions and water clearness. The VIS and NIR region is also the part of the EM spectrum where the changes in radiatively active constituents, such as chlorophyll, and water quality parameters, such as TSM (Total Suspended Matter) and CDOM (Colored Dissolved Organic Matter), can be detected. (Miller et al., 2007)

Sea surface salinity (SSS)

Measuring sea surface salinity (SSS) is essential for determining global water balance and evaporation rates. Ocean salinity is mostly estimated using passive microwave sensors and *in situ* technologies. The microwave radiation emitted from the ocean surface is related to the absolute temperature and emissivity of the sea water. Emissivity of sea water is mostly determined by the salinity of water. Thus, by measuring the sea water temperature with some other method (e.g. by thermal IR) the sea water salinity can be estimated. (Klemas, 2011)

Sea surface temperature (SST)

Sea surface temperature (STT) can be measured using passive microwave and thermal infra-red instruments. Thermal infra-red sensors are commonly using spectral bands at long-wave infra-red (10-12.5 µm) and short-wave infra-red (3.7-4.2 µm) to estimate STT, because they are sensitive to thermal emission and semi-transparent to atmosphere (Miller et al., 2007). Thermal radiation from the sea surface can also be detected using microwave RS at frequencies between 10-100 GHz, wherefore passive RS also used in STT estimation. The benefit of passive microwave RS is the ability to measure through clouds (Langille and Buckley, 2002).

Table 6 Summary of RS technologies and their applicability for maritime monitoring

RS technology	Applications	Limitations	Benefits

Satellite SAR	• Sea Surface Winds (SSW)
	• Sea Ice
	  ○ Extent
	  ○ Thickness
	  ○ Drift
	  ○ Icebergs
	  ○ Ice type
	  ○ Edge
	• Oil spill detection
	• Vessel detection
		• Limited during heavy rain
		• Limited during strong winds and rough seas
			• Independency of solar illumination (can measure at night)
			• Can measure through clouds and fog

Satellite passive microwave	• Sea Surface Winds (SSW)
	• Sea Surface Salinity (SSS)
	• Sea Ice
	  ○ Concentra tion
	  ○ Drift
	  ○ Thickness
	• Oil spill detection
		• Poor spatial resolution	• Can measure through clouds and fog
			• Independency of solar illumination (can measure at night)

Satellite Optical RS	• Ocean color • Sea Ice ○ Extent • Oil spill detection (mostly UV & thermal IR) • Vessel detection	• Cannot penetrate clouds, except at partially at thermal IR	• Availability of data • Multi-wavelength data • Can have very good spatial resolution

Altimeter	• Wave height
	• Sea level t
	• Sea Ice
	  ○ Extent
	  ○ Ice bergs
	  ○ Thickness
	  ○ Edge
		• Limited spatial resolution and coverage	• High resolution range measurement

Scatterometer	• Sea Surface Winds (SSW)
	• Sea Ice
	  ○ Extent
	  ○ Ice type
	  ○ Edge
		• Limited spatial resolution and coverage	• Accurate wind speed determination

Satellite Lidar	• Ocean color • Oil spill detection	• Limited coverage • Spatial resolution • Limited by cloudiness • Usually single wavelength	• High resolution range measurement
Airborne RS (Lidar, imagery)	• Sea ice • Oil spills • Ocean color • Vessel detection • Wave height • Sea surface winds Sea surface salinity	• Limitedcoverage • Cost	• High spatial resolution • Not limited by cloudiness if flown below clouds
UAV	• Same as airborne	• Limited coverage • Limited usage during poor weather conditions	• High spatial resolution • Not limited by cloudiness
In situ	• All	• Poor coverage	• Good spatial resolution • Good measurement accuracy

5.3 EO satellites for maritime environment monitoring

This Section includes information about the current and future satellite missions which have ocean RS as one of their key focus areas. The information is mainly summarized from CEOS (Committee on Earth Observation Satellites) Missions, Instruments and Measurements database (CEOS, 2015) and ESA's Earth Observation Portal database (ESA, 2015).

5.3.1 European Space Agency (ESA)

Sentinels

The on-going European EO programme Copernicus has already launched its first Sentinel EO satellite into the orbit and more satellites will be launched in the near future. Copernicus consists of several Sentinel satellites, each designed for specific applications. Most interesting Sentinel satellites for ESABALT are the Sentinel-1 SAR satellites and Sentinel-3 optical/microwave satellites whose one of the main objectives is to produce data for maritime monitoring, especially in the Baltic Sea region. A major benefit of Copernicus programme is the free of charge data policy.

Sentinel-1A satellite is now operational and currently providing new valuable data for maritime monitoring. In future, Sentinel-1 constellation will be completed with Sentinel-1B (launch 2015) satellite which will enable daily coverage for the Baltic Sea, improving the quality and confidence of the real-time, near-real-time and forecasting maritime products.

Due to the significance of the Sentinel-1 constellation for maritime monitoring, the four data acquisition modes of the Senteinel-1 satellites are briefly described:

- Stripmap (SM):
  - 80 km swath width with 5 m by 5m spatial resolution
  - Stripmap mode is used only in exceptional cases to support emergency management actions.

- Interferometric Wide Swath (IW):
  - 250 km swath width at 5 m by 20 m spatial resolution
  - Main acquisition mode over land
- Extra-Wide swath (EW) :
  - 400 km swath with spatial resolution of 20 m by 40 m
  - The EW mode is aimed primarily for use over sea-ice, polar zones and certain maritime areas, in particular for ice, oil spill monitoring and security services.
- Wave (WV):
  - 20 km by 20 km vignettes with 5 m spatial resolution

Setinel-1 data products will offer Level-2 Ocean products which are especially designed for wind, wave and currents applications. These products will contain three geophysical components, including Ocean Wind Field (1 km by 1 km), Ocean Swell spectra (20 km by 20 km) and Surface Radial Velocity (1 km by 1 km).

Maritime environment monitoring is also one of the main objectives of Sentinel 3A & 3B satellites. These identical satellites will be carrying several RS instruments that can be utilized in ocean RS. These instruments include:

- OLCI: Ocean and Land Colour Instrument
- SLSTR: Sea and Land Surface Temperature Instrument
- SRAL: SAR Radar Altimeter
- MWR: Microwave Radiometer.

The main objective of the Sentinel-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface color with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring.

METOP

ESA also has operational meteorology METOP-satellite program whose objective is to ensure continuity and availability for operational purposes of polar meteorological observations from the “morning” orbit to the global user community. The satellites will be carrying optical and scatterometer instruments.

SMOS

SMOS is an ESA Explorer Opportunity science mission, whose main science objective is to demonstrate observations of SSS (Sea Surface Salinity) over oceans and SM (Soil Moisture) over land to advance climatologic, meteorologic, hydrologic, and oceanographic applications.

5.3.2 NASA

Jason-3

Jason-3 is the follow-on altimetry mission of Jason-2 / OSTM led by the operational agencies: NOAA, EUMETSAT, and CNES. The objective of the Jason-3 Mission is to provide continuity to the unique accuracy and coverage of the TOPEX/Poseidon, Jason-1 and OSTM/Jason-2 missions in support of operational applications related to extreme weather events and operational oceanography and climate applications and forecasting.

Suomi NPP

Suomi NPP is weather satellite mission initiated in 1998, whose primary mission objectives is to demonstrate the performance of four advanced sensors and their associated Environmental Data Records (EDR), such as sea surface temperature retrieval and to provide data continuity for key data series observations initiated by NASA's EOS series missions.

Terra & Aqua

The focus of Aqua and Terra missions is the multi-disciplinary study of the Earth's water cycle, including the interrelated processes (atmosphere, oceans, and land surface) and their relationship to Earth system changes. The data sets of Aqua provide information on cloud formation, precipitation, and radiative properties, air-sea fluxes of energy, carbon, and moisture and sea ice concentrations and extents.

SAC-D/Aquarius

SAC-D/Aquarius is a multi-sensor mission covering ocean, land, atmosphere and space environments. The main objective is to contribute to the understanding of the total Earth system and the consequences of the natural and man-made changes in the environment of the planet. The primary science goal is to study the processes that couple changes in the water cycle and ocean circulation, and influence present and future climate, by measuring sea surface salinity (SSS) variations globally for at least three years.

The Landsat-7 and 8 satellite

The objective of the Landsat-7 and 8 satellite is to extend and improve upon the long-term record of medium-resolution multispectral imagery of the Earth's continental surfaces provided by the earlier Landsat satellites.

ICESat-2

ICESat-2 is a NASA follow-up mission to ICESat with the goal to continue measuring and monitoring the impacts of the changing environment. The ICESat-2 observatory contains a single instrument, an improved laser altimeter called ATLAS (Advanced Topographic Laser Altimeter System). ATLAS is designed to measure ice-sheet topography, sea ice freeboard as well as cloud and atmospheric properties and global vegetation.

5.3.3 NOAA

NOAA –satellites, are a series of Polar Orbiting Environmental Satellites (POES) whose objectives are to provide an uninterrupted flow of global environmental information in support of operational requirements for: global soundings, global imagery, global and regional surface and hydrological observations

5.3.4 China

FY-3

The FY-3, optical and passive microwave satellite series of CMA/NSMC (China Meteorological Administration/National Satellite Meteorological Center), represents the second generation of Chinese polar-orbiting meteorological. Key aspects of the FY-3 satellite series include collecting atmospheric data for intermediate- and long-term weather forecasting and global climate research.

HY-2

HY-2 is a second generation ocean observation/monitoring microsatellite series with scatterometer and altimeter instruments. The objective of HY-2 is the measurement of ocean dynamic and environmental parameters in the microwave region. The requirements call also for the collection of data on marine wind setup (wind vector), marine surface height, and SST (Sea Surface Temperature), along with aero-marine forecasts for the prevention and relief of disaster.

5.3.5 CNES

SARAL

SARAL is a cooperative altimetry technology mission of ISRO (Indian Space Research Organization) and CNES (Space Agency of France). The overall objectives of this mission are to realize precise, repetitive global measurements of sea surface height, significant wave heights and wind speed. Prime payload of the SARAL mission is the AltiKa, altimeter, which will be the first spaceborne altimeter to operate at Ka-band.

5.3.6 CSA

RADARSAT-2

RADARSAT-2 is an advanced state-of-the-art SAR technology follow-on satellite mission of RADARSAT-1 with the objective to continue Canada's RADARSAT program and to develop an Earth Observation satellite business through a private sector-led arrangement with the federal government.The key priorities of the mission respond to the challenges of the environmental monitoring, managing natural resources and performing coastal surveillance. Radasat-2 imagery is operationally used for example in sea ice mapping in Baltic Sea area.

5.3.7 JAXA

ALOS-2

ALOS-2 SAR satellite is the follow-on JAXA L-SAR satellite mission of ALOS (Daichi). The overall objective of the mission is to provide data continuity to be used for cartography, regional observation, disaster monitoring, and environmental monitoring.

5.3.8 DLR

TanDEM-X / TerraSAR-X

The primary goal of the innovative TanDEM-X/TerraSAR-X SAR satellite constellation is the generation of a global, consistent, timely and high-precision DEM (Digital Elevation Model). The secondary mission objectives includes, for example, moving target indication, measurement of ocean currents and the detection of ice drift.

5.3.9 Italy

COSMO-SkyMed

Italian COSMO-SkyMed (Constellation of Small Satellites for Mediterranean basin Observation) is a four SAR satellite constellation. The overall objective of this program is global EO and the relevant data exploitation for the needs of the military community as well as for the civil community. Example application areas of the program is defense and security, risk management and monitoring marine and coastal environments.

5.4 Available maritime services utilizing EO data

EO technologies are already operationally utilized in several maritime services. The following sections present some of these services which could be useful for ESABALT.

MyOcean2

MyOcean2 is an EU FP7 project which aims to establish Ocean Monitoring and Forecasting system of the Copernicus (former GMES) Marine Service users. The system will operate in all marine application, including maritime safety, marine resources, marine and coastal environment and climate, seasonal and weather forecasting. Currently, MyOcean2 service is at pre-operational state, but during 2014 the service will be advanced to full operational service. MyOcean2 service utilizes results and services produced in the precursor EU projects, such as MERSEA, POLARVIEW and MARCOAST.

The main activities of MyOcean2 service are:

- Data acquisition from the ground segment of the space-based observation systems and in situ networks;
- Acquisition of atmospheric data, such as winds, temperatures, fluxes, from National Meteorological Services and ECMWF;
- Compilation of these data into quality-controlled datasets at Thematic Data Assembly Centres suitable for the generation of more extensive datasets for subsequent use, analytical products and assimilation by ocean models.
- Running numerical ocean models in near real time to assimilate thematic data and generate analyses and forecasts to an agreed and generally perpetually repeating cycle.
- Preparation and delivery of products suitable for external service provision.

The main products currently available in MyOcean2 service are sea surface temperature, ocean color, ocean salinity, ocean currents, sea level, sea ice, surface winds and fluxes, and in-situ data. Products include forecast, near real time, multi-year and time invariant products.

Reference: (MyOcean, 2014)

CleanSeaNet

CleanSetNet is European Near Real Time oil spill monitoring and vessel detection services. It has been operated by the European Maritime Safety Agency (EMSA) since April 2007 and it is a recognized Copernicus (former GMES) service. CleanSetNet service is based on radar satellite imagery, covering all European seas.

CleanSetNet provides information about possible oil spills, pollution alerts and related information to the operational national maritime administrators within EU states 30 minutes after satellite image acquisition. Vessel traffic information, such as AIS data, is included in CleanSeaNet systems, which enable the detection and identification of discharging vessels. Vessel detection using SAR imagery is also regular feature of CleanSeaNet servive.

Currently, CleanSeaNet utilizies satellite imagery from RADARSAT-2 and COSMO-SkyMed SAR-satellites. In the near-future, ESA's new Sentinel-1 satellite will be added to the system.Each European coastal state has a free access to CleanSeaNet service through a web application which is used to visualize the oil spill alerts. The web application also provides users supplementary information, such as oil drift modelling (forecast and backtracking), optical images and oceanographic and meteorological information.

Reference: (CleanSeaNet, 2014)

KSAT (Kongsberg Satellite Services)

Kongsberg Satellite Services (KSAT) is a Norwegian commercial company providing services utilizing Earth observation data. KSAT offers services especially within maritime sector using data from several optical and radar satellites. KSAT's services include oil spill and vessel detection service and ice navigation service. KSAT's oil spill detection data is also utilized in CleanSeaNet service. (KSAT, 2014)

5.5 Previous and on-going projects utilizing EO data in maritime applications

Numerous previous and on-going research has been conducted to evaluate EO data in various maritime applications, such as sea ice and monitoring, oil spill detection and maritime surveillance. Next sections will present some of the projects whose results could be utilized in ESABALT.

5.5.1 Maritime Surveillance projects

SAGRES (Service Activations for Growing EUROSUR's success)

SAGRES will support the pre-operational test and deployment of the high-time critical CONOPS components via the EUROSUR network.

Main SAGRES goals are:

- To test the usefulness of the CONOPS services to support the operational missions that users are conducting in the field of border surveillance.
- To bridge the gap between research and the operational set-up
    - To identify relevant data sources beyond space-borne data
    - To define criteria for data acquisition and satellite-tasking
- To provide a comprehensive view to multi-source and data fusion exploitation.
- To include outcomes of FP7 projects currently on going,
- To review future services based on evolution and availability of technology

Reference: (SAGRES, 2014)

NEREIDS

NEREIDS aims to enhance integrated, automatic and unsupervised ship monitoring service capabilities for maritime situational awareness and, in turn, to support advanced and efficient decision making tools. This will be tackled by assuming advanced technological techniques related with SAR imagery processing (automatic ship detection, land masking and ship classification) and with data merging / fusion of ancillary sources of information.

Reference: (NEREIDS, 2014)

Dolphin

DOLPHIN is an EU Copernicus research and development project in the field of Maritime Surveillance. DOLPHIN project will develop new methods and algorithms for processing satellite radar and optical images in order to improve the detection and monitoring of seafaring vessels.

Application areas:

- Border Surveillance
- Traffic Safety
- Fisheries Control

The aim of the project is to optimize existing space-based observation systems to provide improved solutions to maritime surveillance users. The following technological gaps will be addressed:

- more timely and reliable information;
- the enhancement of situational awareness;
- the increase of reaction capabilities through the provision of reliable decision support tools.

Reference: (Dolphin, 2014)

5.5.2 Marine Environment Monitoring projects

MyWave

The main goal of MyWave is to lay a foundation for a future Marine Core Services (MyOcean) that includes ocean waves. To reach this goal the project will:

- Increase the use of EO data in wave forecasting systems by importing data processing algorithms and data assimilations.
- Improve the physics in current wave models and to provide a framework for coupled model systems that are fully coupled to atmosphere and models.
- Establish a new standard for probability wave forecast based on ensamble methods. i.e. systems where a large number are made based on small difference in the initial conditions.
- Derive standard protocols for validation of wave forecast.

Reference: (MyWave, 2014)

MAIRES

The overall objective of the MAIRES proposal is to develop methodologies for satellite monitoring of Arctic glaciers, sea ice and icebergs. The proposal will demonstrate the benefits of combining Earth Observation data from European and Russian satellites for operational mapping, interpretation and forecast of land and sea ice variations in the Eurasian Arctic with subsequent applications in the socioeconomic sector. The results of the proposal will contribute to improved understanding of changes in land and sea ice in response to climate change in the Arctic. (MAIRES, 2011)

5.6 Evaluation of EO Technologies for ESABALT

5.6.1 Evaluation criteria

There are several factors that have to be taken into account when evaluating the applicability of EO technologies for maritime applications and ESBALT system. EO data has the characteristics of the instrument that was used to produce the data. The following factors and questions need to be considered while evaluating different EO technologies for ESABALT system:

- spatial resolution
    - How small objects or details can be detected? (e.g. detecting smaller vessels or the exact edge of the ice sheet requires better spatial resolution)
- spectral resolution
    - How small spectral changes can be detected? (e.g. detecting small changes in ocean color requires better spectral resolution)
- spectral range
    - How wide spectral range is needed for different tasks?
- data coverage
    - How large areas can be observed at the same time?
- frequency of data acquisition / temporal resolution
    - How often data is acquired and available from the same area?
- availability of the data
    - What is the cost of the data?
    - How fast is the data available for users after the data acquisition?
    - How is the data delivered?
    - Is some kind of data processing required from the user?
    - Data format (raster or vector)?
- data acquisition technique
    - Is data needed day and night and in all weather conditions?

5.6.2 Requirements of ESABALT system

- ESABALT system is a situational awareness system where real or near-real time and reliable forecast information is needed for decision making, such as rerouting. Therefore, the most important requirement of RS technologies for ESABALT system is the frequency of data acquisition and the availability of the data. The data must be automatically downloadable and accessible by ESABALT system immediately as the data is available.
- Spatial and spectral resolution of the data produced by the RS technology must be high enough to recognize larger seafaring vessels and possibly hazardous oil spills and ice floes.
- The data must cover as large area as possible (in the Baltic Sea).
- The data cost must be as low as possible.

5.6.3 Evaluation of different RS techniques

Compared to airborne RS, satellite EO is typically cheaper to wide areas. Satellite-based RS can produce data from wide areas with a single image, whereas airborne sensors require several flights to cover as wide area. On the other hand, airborne RS is more beneficial in producing detailed data from smaller areas, such as verification of possible oil spill in specific area. Airborne RS is also applicable solution if spatially and spectrally accurate data is needed from wide areas and there is no requirement of the data being immediately available. In the ESABALT system up-to-date EO data and therefore satellite-based sensors are considered to be more beneficial than airborne systems.

The main existing satellite EO technologies are based on optical and microwave satellite sensors. Benefit of optical satellites are their capability to produce multi- or hyperspectral imagery with wide spectral range enabling various maritime applications, such as water color, sea surface temperature and target or ship detection. However, optical sensors are mostly dependent on solar radiation which excludes night-time imaging and they require cloud-free weather in order to image the land or marine environments. This can be a major disadvantage in areas with high cloudiness or fogginess. Thus, satellite-based microwave instruments which are not constrained by cloudiness or solar illumination are considered more applicable for the ESABALT system than optical satellite RS data. ESABALT requires mostly data with spatial resolution better than passive microwave instruments can produce and thus SAR instrument that have better spatial resolution are considered more suitable for the ESABALT system. SAR instruments are operationally used in various maritime applications that are essential for ESABALT system, such as ice sheet mapping, oil spill detection and vessel detection.

Many of the already operational maritime services utilizing EO data are using SAR imagery as their main component. The newly launched Sentinel 1A satellite that has free data policy will uplift the use of SAR in maritime services even more. However, usually operational maritime services using EO data are using models that utilize data from as many instruments and data sources (e.g. satellite RS and *in situ* measurements) as available, which is the most reliable method of utilizing EO data in maritime monitoring.

6 Communication technologies

This section presents an overview of the state-of-art techniques, policies and procedures for effective communication between ships and between ship/shore-based agencies. Marine communication has evolved significantly over the years, with the use of sound, light and then electronic codes and signals to speak between ships and between the ship and shore. The information to be communicated can be any subset of the following (Unit 7 2014): distress calls, casual calls, navigation and tracking, status updates, clearance calls from coast-guard or port authorities, etc. Typical electronic communication involves radio telephony, radio telex, radio telegraphy, global marine distress systems, electronic charts, and satellite communication systems, among others. In the sections to follow we classify these technologies for easy identification and description into various categories such as, commercial, non-commercial (free), industrial, academic, ship-based, land-based, etc. Finally, we identify which upcoming communication technologies, if any, could be introduced in the maritime environment as well existing hurdles, e.g. in terms of cost, limitations of data transmission bandwidth, etc., towards achieving the next step in the evolution of maritime communication technologies.

6.1 Communications Standards

As described in (Choi et.al. 2013) and (Yun et.al 2012), communication standards consist of the geographic extent (reach) of the different communication technologies and their standardized frequency spectrum utilization properties.

Conventional maritime wireless communication is mostly based on voice communication, which uses radio devices operating on the Medium Frequency (MF, 300 kHz - 3 MHz), High Frequency (HF, 3 MHz - 30 MHz), Very High Frequency (VHF, 30 MHz - 300 MHz) bands, and even higher-frequency satellite communication systems. The radio devices installed on a vessel are decided according to its size and sailing area. International Maritime Organization (IMO) and International Telecommunications Union (ITU) have defined the appropriate radio types for each type of sailing vessel.

In the case of satellite-based communication systems, there are four frequency bands that are useful for applications in the domain of maritime communications: L-band (1 GHz - 2 GHz), C-band (4 GHz - 8 GHz), Ku-band (11.2 GHz- 14.5 GHz), and Ka-band (26.5 GHz-40 GHz).

According to the IMO, the seas can be categorized into four areas based on their distance from the shore. These categories and their corresponding communication frequency band are shown in the Table 7.

6.2 Communication Mediums

This section describes the various communication technologies in terms of mediums and channels available in the maritime domain. Here we do not consider traditional communication techniques such as light signaling, sound, telegraphy, etc. but rather focus on modern electronic wireless systems capable of communicating voice and data over wide bandwidth high frequency channels. Examples of such systems are; satellite-based, microwave links, WiFi, high gain antennas, and VHF data exchange system.

Table 7. Categories of sea areas and their properties

Sea Area	Distance From Coast	Name	Communication Technology
A1	50 km – 100 km	Coastal VHF	VHF
A2	200 km – 400 km	Medium Wave Range	MF
A3	76° N - 76° S	High Seas	INMARSAT/HF
A4	Worldwide	High Seas including Arctic	EPIRB, HF

* EPIRB = Emergency Position-Indicating Radio Beacon

(Jakovlev et.al 2013) does a study to show possibilities to increase the adaptability, availability and autonomy of the waterborne transportation through enhanced autonomy for ship systems and ships by using wireless communication technologies for ship-to-ship and ship-to shore communications in a networked and integrated environment. Providing and enhancing the storage and interchange of different information, such as technical, administrative, commercial, environmental and navigational information increases the autonomy of ships as well as their adaptability and availability.

Current maritime wireless communication systems are based on MF, HF, VHF radios for close-range ship to shore communications and satellite communications for long-range ship-to-ship and ship-to-shore communications. These maritime radio technologies are limited in their communication bandwidth. On the other hand, using satellite communication is too expensive for some commercial services. To solve these problems, (Choi et.al. 2013) proposed an improved maritime communication technology to transmit large multimedia data using WiMAX (IEEE 802.16j).

In terms of satellite communication systems in the maritime domain, there are two broad service categories (Bradbury 2013): Mobile Satellite Services (MSS) and Very Small Aperture Terminals (VSAT). MSS is offered by technologies such as Inmarsat and Iridium, and offer volume-based charging. Their bandwidth is relatively constrained, at maximums of around half a Mb/s. Their advantages are ease of installation and, in Iridium's case, coverage all the way to the poles.

MSS terminals are typically mobile, whereas VSAT requires the installation of more permanent equipment. The installation costs are higher generally, but it does provide reliable continuous service, rather than the piecemeal communications typical of MSS. It also offers more bandwidth, extending up to 4Mb/s. For vessels that restrict communications to the bare essentials, MSS can prove a cheaper option. However, for vessels with heavier communications needs, such as cruise ships, or oil and gas rigs, VSAT is often preferable.

VSAT is purchased for a variety of reasons, depending on the nature of the vessel. Crew welfare is a particularly important issue. Sourcing crew has been a chronic problem for logistics, fishing, and other vessel types. Providing the facility to call home, exchange email, or even check social media websites, can help to attract crew members to uncomfortable - and sometimes dangerous - employment at sea. Cruise ships are also in a position to profit from the use of VSAT, because they can offer it as a value-added service for customers; and they can offer it internally to third-party retailers installed on the ship who need to resolve credit card transactions.

Table 8. Solutions for satellite-based communication between ship and shore

System	Band	Range	Bandwidth	Comment
Inmarsat C	L	A3	9.6 kbps, packet oriented	GMDSS, Used for short e-mails and messages
Inmarsat Fleet 77/BGAN	L	A3	128-450 kbps	GMDSS (not BGAN yet), supports Internet
Iridium	L	A4	134 kbps (Open Port)	Also coverage in Arctic.
VSAT shared link	C, Ku, Ka	A1-A3	Any, typical 64-512 kbps. Shared by several users.	Coverage varies with system, normally not deep sea.
VSAT dedicated link	C, Ku, Ka	A1-A3	Any, dependent on price. Dedicated capacity to user.	Coverage varies with system and (high) price.
Other (Orbcomm, Globalstar, Thuraya, ARGOS)	L, S, C, Ku, Ka	A1-A4	Typically low, usually up to telephone.	Either bent pipe systems or store and forward.

Technical and administrative operations are becoming more reliant on continuous digital communication with shore parties (Rødseth 2012). Some of these existing and emerging requirements are discussed in (Rødseth 2009) and (Rødseth 2006). (Rødseth 2012) presents a discussion on new communication needs driven by the IMO e-Navigation and EU's e-Maritime initiatives. Table 8 describes the various solutions for satellite-based communication between ship and shore.

6.3 Commercial Services

There are a number of providers of commercial communication services which provide custom and generalized solutions to the maritime community. Examples of such providers are Norphonic, Frequentis, Globe Wireless, INMARSAT etc. This section describes some of their product offerings in more detail.

Norphonic (Norphonic 2015) is a Norwegian company that specializes in the production of high performance communications for offshore and marine areas through delivering Heavy Duty VoIP telephones. Other products on offer include, offshore fiber networks, ship to shore communications over an industrial Ethernet, ship to shore VoIP network via satellite, and offshore LAN / VoIP network. Furthermore, Modbus TCP, UDP and SNMP open standard protocols are included in all Norphonic VoIP models assisting in integrating Norphonic offshore telephones with the existing ship SCADA system or overall data reporting system.

Frequentis (Frequentis 2015) is a UK based company that offers maritime communication systems which are land-based and support ship-to-land, land-to-land and ship-to-ship communication. The joint radio and telephone infrastructure promises fast, safety-critical communication between all parties involved. This infrastructure is managed from designated communication centers. Technologies and services on offer include VoIP, Radio over Internet Protocol (RoIP), Coastal Radio Services (CR), Coastal Surveillance Solutions (CSS), Port Communication

Solutions (PCS), Rescue Coordination Centers (MRCC), and Vessel Traffic Services (VTS).

Globe Wireless (part of **INMARSAT**) provides a new HF/MF digital maritime mobile system integrating land-based, sea based, satellite-based and internet-based communication infrastructure, as described in (Nicholls 2012), (Globe Wireless 2015).

6.4 Research Projects

The following research projects have been studied as examples of innovation in the domain of maritime communication methodologies:

The **'EfficienSea' project** (EfficienSea 2015) aims to implement solutions for efficient, safe and sustainable traffic at sea, and especially the Baltic Sea area. The four primary areas under investigation were, Competencies and Recruitment Challenges, e-Navigation, Vessel Traffic Data and Maritime Planning, and Dynamic Risk Management. The primary output of this project in terms of communication technology was the EfficienSea AIS VHF Datalink Management application (EAVDAM). EAVDAM is a software tool facilitating transnational cooperation on management of the Automatic Identification System (AIS) frequencies to ensure the integrity of the AIS VHF Datalink within the Baltic Sea Region, the European Union and ultimately on a global scale.(Chang 2012) suggests a technique for planning network coverage and connectivity based on density of ship traffic. Maritime mesh network needs practical methods and tools for the evaluation and planning based on local vessel traffic data. This paper proposes a novel approach which uses density-based clustering and vessel traffic data collected via coastal AIS networks. Such an approach is demonstrated to be an effective tool to spatially evaluate the viability and plan shore sites for better network coverage and connectivity.

(Zhou 2013) and (Boreli 2009) describe the **TRI-media Telematic Oceanographic Network (TRITON) project**, which aims to develop a high-speed and low-cost maritime communication system. The system is a wireless mesh network between ship, lighthouse, buoys using IEEE 802.16/16e. The network is feasible in shipping lanes with a high density of ships, very applicable to the Baltic Sea corridor. The system also considers the use of an intelligent middleware to allow communications to switch back to a satellite link in cases where neighboring ships are sparse or at locations far away from mesh base stations. Protocol enhancements to both the Medium Access Control (MAC) and networking layers and a hardware design that features multiple transceivers and the implementation of antenna switching to counter sea wave reflection and rocking problems is also studied.

(iN.SG 2015) describes the **Wireless-broadband-access for SeaPort, or Wiseport, project**. This was a project implemented by The Maritime and Port Authority of Singapore (MPA). With the infrastructure in place ships can now enjoy wireless mobile broadband connectivity while operating in the Port of Singapore, up to 15km from Singapore's southern coastline. And finally, (WiredOcean 2015) describes the **'WiredOcean' concept**, which includes broadband, IP based TV, internet and communication using hybrid satellite and DVB systems.

6.5 Search and Rescue Services

This evaluation of communication technologies used at sea would be incomplete without discussing one of the most important applications of these technologies: communicating distress and aiding in the consequent search and rescue procedures.

- Galileo SAR
- Global Maritime Distress and Safety Systems (GMDSS) and Cospas-Sarsat

6.6 Communication Security

Integrated navigation system data communication is critical aspect regarding the security issues. INS is normally totally isolated from the external world and networks. If external communication is required, it is established via secure gateways using available communication channels. Safety of navigation must be ensured in all circumstances. Separate isolated sensor network and INS network with limited and secured connectivity to external sources are mechanisms for continuous safe operation of the vessel.

ESABALT system concept from the vessel system perspective is eNav type of application. ESABALT data communication solution must take into account same security aspects related to vessel communication and system connectivity.

6.7 Miscellaneous Aspects of Communication

6.7.1 Communication link quality aspects

Data communication link quality on-board the vessel is not at the same level as in shore based systems. Vessel located close to shore or at port may have good bandwidth and low latency available for applications. Anyhow, at sea available bandwidth is limited and latency is higher (sometimes up to 30 seconds) and also changing significantly. Normally TCP/IP based high bandwidth requiring real time applications are not working properly on-board the vessels at sea.

Applications must be designed so that required data bandwidth is limited and/or system is tolerable against latency variation. Also ESABALT system concept must take these facts into account.

6.7.2 Data communication at Baltic Sea

Distances at the Baltic Sea from the shore line to the vessel are often such that communication is available using mobile 3G equipment. It is very common to use 3G network communication when it is available. Some lower end vessels have it as the only data communication channel and higher end vessels may have more sophisticated multi-port routers that utilize 3G when it is available instead of more expensive satellite communication.

Other aspects of maritime communication that are addressed in this study include: Standardization of Information form, Automation of communication, Watermarking of information for automatic identification.

7 Automatic Identification System (AIS) technologies

The Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel tracking services for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. When satellites are used to detect AIS signatures then the term Satellite-AIS (S-AIS) is used. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport.

Information provided by AIS equipment, such as unique identification, position, course, and speed, can be displayed on a screen or an ECDIS. AIS is intended to assist a vessel's watch standing officers and allow maritime authorities to track and monitor vessel movements. AIS integrates a standardized VHF transceiver with a positioning system. Vessels fitted with AIS transceivers and transponders can be tracked by AIS base stations located along coast lines or, when out of range of terrestrial networks, through a growing number of satellites that are fitted with special AIS receivers which are capable of de-conflicting a large number of signatures. IMO requires AIS to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 or more, and all passenger ships regardless of size (AIS IMO, 2015).

7.1 Standard ship AIS equipment

SOLAS rules require AIS (Automatic Identification System) to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 or more, and all passenger ships regardless of size.

Standard AIS equipment is connected to GPS, gyro, speed log, Inmarsat, radar, ECDIS and alarm system. AIS has capability to receive AIS targets reported by other vessels nearby the vessel. Reported tracks are visualized on ECDIS and radar screens with AIS symbols. Vessel’s reported AIS data (vessel name, size etc.) can be checked by clicking the symbol.

Vessel’s own AIS data is sent out using VHF frequency (156,025 – 162,025 MHz) and maximum 12.5 W transmitter power.

AIS equipment have pilot plug for external PC connectivity to receive other ship’s AIS locations around the vessel. This interface can be used by pilots to connect their equipment with AIS.

7.2 Possibilities of complementing existing standard

7.2.1 Initial findings - Available slots in AIS standard

Message	Spare bits	Title
1,2,3	3	Position report
4	9	Base station report
5	1	Ship static and voyage related data
9	7	Standard SAR aircraft position report
14	968	Safety related broadcast message
18	8	Standard class B equipment position report

19	8	Extended class B equipment position report
21	1	Aids to navigation report

7.2.2 What can be added to existing standard?

Route to the next port of call, including all waypoints (WPs) or at least 5 next WPs – transmitted by each ship in Message 5: Ship static and voyage related data. Unfortunately there is only one spare bit in message 5 in two slots.

Solution: to add third, fourth, fifth etc. slots to this message to accommodate a/m information which are crucial to predict behavior of other ships particularly in collision situation.

Meteorological and navigational warning – transmitted by each ship in Message 14: Safety Related broadcast message. There are 968 spare bits in message 14. It gives 161 available characters (6-bits ASCII) to send a/m information. Unfortunately this option is very seldom used by vessels to transmit a/m information. It’s usually used to transmit test message or “social” information.

Solution: awareness of seafarers about the opportunities.

Anti-collision maneuver – transmitted by each ship in Message 14: Safety Related broadcast message. Such information should be transferred to AIS and transmitted by AIS automatically, because the navigator in collision situation has no time to do so. This information is crucial for another vessel/vessels involved in collision situation.

Solution: direct and two way transmission between anti-collision system and AIS

7.3 Projects related to AIS

The **AIS+ project** [14] aims to implement and develop a software application that allows the maritime user access to the novel Application-Specific Messages of the AIS. These messages include e.g. weather, water level and route information from coastal stations. The ship can also report e.g. route plans and dangerous cargo information. The application includes a user interface for visualizing the received information and for sending necessary reports. The applications will be implemented according to the Open Source principle which provides a strong basis for a wide utilization and further development in the future.

8 Other existing user-driven solutions for enhancing transportation safety and situational awareness

This chapter describes the state-of-the art of the use of user-driven solutions, namely solutions processing data collected by crowdsourcing, for transportation. Also, the different nature of the use of crowdsourcing in maritime operations is discussed.

8.1 Crowdsourcing

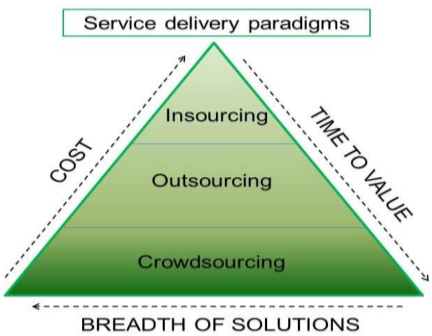
Crowdsourcing means the use of an undefined network of people to collect information to be used for a certain purpose (Franzoni & Sauermann 2014). One of the most known early examples is Wikipedia.

Based on Gao et al. (2011) the use of crowdsourcing data for safety applications has the advantage of the distribution of the data being fast, the data is provided from multiple sources and with various forms and the data is automatically geo-tagged. However, its defects are the coordination of the use of the data, the accuracy and reliability of the data are difficult to be verified and the security as well as privacy issues of transmitting the data are difficult.

Probably deriving from the before mentioned problems, crowdsourcing applications for enhancing transportation safety were still on the research stage and the already implemented systems were mainly for providing better situational awareness for enhanced travelling comfort. Both types of applications are described below in the context of maritime, land, rail and air transport. Finally the use of social media for crowdsourcing instead of the conventional transmission of information, namely the distribution of information collected by the sensors of the user's device, is discussed.

8.2 Distribution of information in maritime operations

Figure below describes the use of crowdsourcing for service delivery based on Econom's blog (Econom 2015). Crowdsourcing is compared to the concepts outsourcing, namely buying services from other service providers outside the client organization, and to insourcing, namely providing the service inside the organization in need. The main benefits of crowdsourcing are that the cost for the service is very low compared to outsourcing and insourcing, while the time to value, namely the fastness of receiving the need data, is high. Also, when the number of crowdsourcing participants is high, the breadth of the solutions is high, e.g. maps, barometry data, and ice awareness. One of the key challenges of maritime-related crowdsourcing is, therefore, attracting a large number of participants.



Comparing three service delivery paradigms: insourcing, outsourcing, and crowdsourcing (Econom 2015)

8.3 Land transport

Waze (Marjanovic et al., 2012) is one of the few already implemented crowdsourcing based transport services. It is a mobile navigation application that passively collects traffic related data from users as well as receives and distributes crowd sourced data from the users, e.g. reports from accidents or police inspections. The service also includes an active community of people updating the maps. Waze is not restricted to any area, but can be used where ever roads exist.

Crowdsourcing has been considered as a tool for improving safety of the intelligent transport in numerous research papers. Aubry et al. (2014) study the use of traffic offence reports made by the service users for improving the immediate safety of the road users as well as providing a tool for the authorities for traffic planning. Zambonelli (2011) suggest the use of crowdsourcing for improved situational awareness making e.g. private parking spaces available for other users when the owner is away or private cars when they are not in use as well as enabling more efficient car-pooling. Many papers discuss the technological implementation aspects of the crowdsourcing based services, e.g. Ali et al. (2012), Gorin et al. (2014).

8.3.1 Pedestrians

The safety of pedestrians may be increased by producing collective emotion maps (Klettner et al. 2013) showing unsafe places in a city. It has been shown that pedestrians prefer the safety and convenience of the route over its shortness (Golledge 1995). Klettner et al. have used the crowdsourcing data for developing a pedestrian navigation system, EMOMAP, for improved safety and amenities.

8.4 Rail Transport

A study was performed in 2011 in the Netherlands where information about the behaviour of the customers was collected by crowdsourcing (van der Wees 2011). The motivation for the Dutch Railways (NS) was to get a better understanding of the customers. They built three different test applications for collecting the user data and analysing the information they provide. The study evaluated if the crowdsourced data provides means for understanding e.g. the satisfaction of the user on the service or the maintenance and for forming user profiles for better directed services. The research envisioned that in the future the crowdsourced data could also be used for detecting technical problems of trains by collecting the user perceptions of e.g. abnormal noises.

8.5 Air transport

Omokaro and Payton (2014) have studied a hypothetical scenario where crowdsourcing would be used to improve the aviation comfort and safety. In their scenario passengers could create a health care database about the symptoms they have experienced in-flight, then the data would be analysed by healthcare experts and the results disseminated to the airline crews for educational purposes. By learning to connect the symptoms to certain health problems the crew would be able to act on the situations before they become severe. Also, crowdsourcing could be used for collecting information about the in-flight air pressure and noise level by using relevant sensors which already exist even in smartphones for some extent. This data could further be used for improving the passenger flight experience. The research also suggests that the passengers could be seen as additional black boxes in the case of an emergency, if their perceptions of for example weather conditions or ambient sounds would be collected by crowdsourcing during the flight.

8.6 Crowdsourcing via Social media

For public transportation the use of social media based crowdsourcing was already reality for at least one third of transit agencies in US and Canada in 2012 (Bregman 2012). Information, such as punctuality, noise levels, and assessments of driver skills, referenced to particular vehicles, routes and times can be obtained via social media (Nunes et al. 2011). The use of crowdsourcing in public transportation has been discovered beneficial especially in exceptional circumstances, for example during a cold weather. There are already a few existing user-driven applications for public transport, two examples presented below, *Moovit* and *Tiramisu*.

Based on (Filippi et al. 2013) the full potential of the social media has not yet been fully deployed but the crowd sourcing applications are still mainly real-time personal applications and not based on the information collected from the social media. However, the research on the benefits of harnessing the social media into the utilization of public transport has been active lately (Greencitystreets 2013). The main difference between the conventional crowdsourcing and the one based on social media is that the former is usually based on the needs of a company as the latter builds on the interest of the users.

8.6.1 Moovit

Moovit provides mobile device users a navigation solution and information about public transportation in over 400 large cities around the world. It fuses the public transport schedule information with crowd sourced content, e.g. reports about the traffic, available seats, cleanliness of the vehicle and position information collected from the users passively.

8.6.2 Tiramisu

Tiramisu (Zimmerman et al. 2011) have developed a smartphone application for the users to log the position information of their travel as well as contribute to the service with additional information, for example of the availability of free seats on the buses and reports about the journey. Until the end of the year 2014 more than 170 000 trips had been reported by the community.

9 Feasibility of the crowdsourcing approach for marine information gathering

This section addresses the feasibility of using a crowdsourcing approach for gathering marine-related information. Maritime transportation, much like aviation, has very stringent safety requirements, and therefore the use of crowdsourcing is more complex than for land transportation purposes. Also, the different roles of information users have to be taken into account. A lesson learned from the MARSUNO pilot project, aiming to achieve better interoperability among maritime monitoring and tracking systems between the authorities of different countries, was that there are issues even on the data collected by the officials of different countries controlling the sea areas the vessels are crossing (MARSUNO 2011). Due to the sensitive nature of maritime transportation, so far the use of crowdsourcing has been limited, and mainly only authoritative data with verified status and provenance have been employed.

9.1 Existing uses of crowdsourcing in marine information gathering

Crowdsourcing has been seen as a useful tool for some maritime operations, as the authority's data have issues with currency and coverage. The possibility to ensure good quality of user-provided data has been studied (Chilton & Mason 2013). One of the maritime crowdsourcing systems already in use is called Argus (Van Norden et al. 2013). It is a crowdsourcing bathymetry system which provides the users with depth data collected using GPS and depth-finding systems of multiple vessels with different sizes. Argus is in use in the United States at the Intracoastal Waterway (ICW), and in addition to the depth data it provides the users with information about navigation hazards like misplaced buoys overlaid on chart displays. Crowdsourcing would be feasible also for addressing the lack of data from inland lakes, as investigated in a project carried out in Denmark for bathymetric data (Vedel & Hansen 2012).

OpenSeaMap is a project addressing the need for easily accessible nautical charts including also navigation data (e.g. beacons, buoys, port information), by aiming to create comprehensive nautical charts by crowdsourcing (OpenSeaMap 2015). OpenSeaMap is a subproject of OpenStreetMap aiming at creating a free map of the whole world (OpenStreetMap 2015).

Use of crowdsourcing for creating ice awareness would improve the safety of vessels especially in Arctic areas. At present, ice monitoring is done by interpreting radar data and using crew's visual perception. (Reid et al. 2014) suggests an ice-aware system using multispectral sensing by a combination of LIDAR, radar, and video. The resulting data are geo-referenced with GNSS measurements and distributed to all vessels nearby.

9.2 Survey-based feasibility assessment

In order to address the question of whether it is feasible to use a crowdsourcing approach for gathering marine-related information, the ESABALT project began by asking maritime users themselves whether they believe crowdsourcing is a viable approach. In a web-based survey, we first asked potential users whether they were familiar with the concept of crowdsourcing. 56.8% of respondents answered that they were familiar with the concept. This can be compared to 84.9% of the respondents answering that they were familiar with the concept of situational awareness. For those survey participants who were not familiar with the concept of crowdsourcing, we next presented a short description of the concept, as it applies in the ESABALT project. Next, we asked participants to answer whether they believed that crowdsourcing would be a feasible method of collecting and exchanging information at sea. A significant majority (86%) responded in the affirmative.

That being said, a sizable minority answered negatively to this question, and this presents some reason for concern. Of those answering that crowdsourcing is not feasible, common reasons given were:

- Accuracy / reliability of information
- Limited available time for ship crew
- Too few ships

We also asked participants to select or list the types of information they believe can be collected via crowdsourcing. The following information types were commonly identified:

- Maritime traffic information (78%)
- Emergency/SOS/Mayday situations (75%)
- Information about potentially hazardous situations (75%)
- Sea ice information (72%)
- Weather information (71%)
- “Near miss” / “close call” incidents (68%)
- Environmental pollution (64%)

The percentages shown after each information type indicate the fraction of respondents who selected this information type from the total number who answered this question. Note that those participants who answered negatively to the earlier question about the feasibility of crowdsourcing were not asked this question at all, so these percentages reflect the views of those who are already amenable to the whole concept of crowdsourcing maritime information.

Next we asked all participants to indicate whether they would participate in crowdsourcing of maritime information, if given the chance and/or technical possibility. 86.4% responded affirmatively. Taken together with the earlier question regarding the feasibility, this indicates that not only do many mariners think crowdsourcing is feasible, they themselves would contribute to the data collection, if given the chance.

At the same time, however, it was noted in the survey results that a new system introduced to the maritime operating environment should not require significant additional interaction or sustained attention of the crew. Traditional methods of situational awareness include monitoring the situation by visual means or through established electronic means (radar, AIS). Thus, an additional system which utilizes crowdsourcing should not detract from the time available for the crew to monitor the situation using these traditional methods. In particular, any new system should exhibit a high level of autonomy and, if possible, it should be integrated into existing systems.

9.3 Assumptions adopted for future feasibility assessment studies

This section outlines some of the guiding assumptions concerning the information exchange processes used in the maritime domain, which are relevant for answering the question of whether crowdsourcing is a feasible approach for marine information gathering.

Assumption 1: Information must flow from shore-to-ship, ship-to-shore, and ship-to-ship. All three types of information flow are expected to be used by the ESABALT system. Shore-to-ship and ship-to-shore are extremely important because centralized information management, for example, through a VTS operator provide a higher level of re-liability and quality assurance for maritime information exchange. However, VTS operators cannot maintain good overall situational awareness without regular updates from vessels, for example, updating of routes when a vessel changes her planned route due to unforeseen circumstances. Lastly, ship-to-ship communication is assumed to be beneficial due to the fact that the ship-to-shore and shore-to-ship links may not be available all of the time and in all locations at sea. In addition, ship-to-ship communication may provide the most timely and reliable means of communication when the information is of critical nature and needs to be exchanged quickly (e.g. maneuvers to avoid collision). Another example of ship-to-ship communication is direct transmission and reception of position and heading data through a vessels' AIS transponder.

Assumption 2: Different vessels have different communication capabilities. In particular, larger vessels, such as commercial cargo or passenger ships are assumed to have greater communication capabilities compared to, e.g. pleasure boats. For example, most commercial ships have VSAT capabilities, which allow them to send and receive data globally, whereas a pleasure boat may have only VHS or cellular radios/phones. VHS may be limited to voice-only communication and cellular phone coverage is generally only available in coastal areas. As a result of this assumption, the ESABALT system must be interoperable with different communication systems, and it must adapt itself based on the communication capabilities of the user terminal.

Assumption 3: Adequate standards for maritime information exchange already exist. Standardized protocols and formats for exchange of maritime information are important because the information must be processes by multiple parties, and furthermore the formats must be machine readable, in order to facilitate automation. Examples of relevant existing standards include NMEA 0183, NMEA 2000, S-57, S-100, S-101, and S-102.

Assumption 4: Information exchange processes should be highly automated. As a result of a survey of potential users, it was apparent that information exchange processes should be highly automated, in order to not burden the crew with additional workload. In addition, automated systems generally require less training, so automation also reduces the training burden created by the ESABALT system.

Assumption 5: Most users are assumed to be cooperative and trustworthy. This is admittedly a strong assumption. The only way to test whether this assumption holds is to make realistic trials using the crowdsourcing approach and to verify the information using all available means. Nonetheless, it is important to consider the trustworthiness of those participating in the collection of information and plan for how to deal with problems related to this.

If an uncooperative or malicious user intentionally provides falsified information, this can have serious consequences for the overall system. The system must have capabilities to identify such users and to restrict them from using the system. It is assumed, however, that most users of ESABALT are cooperative and trustworthy. This is a reasonable assumption, especially if authentication is required to access or otherwise use the system. If a user behaves contrary to the guidelines and principles in the end-user license agreement, then he or she will be banished from the system. Because most users are linked to a ship or shipping company and have a reputation to uphold, they will be motivated to operate according to established procedures and guidelines.

9.4 Summary

It is perhaps still too earlier to answer definitively whether the crowdsourcing approach for marine information gathering is feasible or not, but based on existing usage, limited user surveys, and initial technological assessments, there is no reason to believe that crowdsourcing is not feasible. It is only real-life trial experiments and building up of operational experience that will finally determine whether this approach can be taken into widespread usage.

There may possibly be two alternate options to approach this subject: the first is to make a Strength Weakness Opportunities and Threats (SWOT) analysis of crowdsourcing approach for marine information gathering on the basis of crowdsourcing implementations presented in Section 8 of this document. The second is to make a short crowdsourcing analysis from technical, economic and organizational points of view.

10 ESABALT Test and Data Collection Campaign in the Baltic Sea

The Finnish Geospatial Research Institute (FGI) as part of two research projects (ESABALT and 'Development of a Mobile Public Precise Positioning Service Based on the National GNSS Network' (P3-Service)), arranged a test and data collection campaign in the Baltic Sea onboard VikingLine MV Amorella (traveling between Turku and Stockholm) in early February. This campaign was planned in the interests of understanding the state-of-art and needs of future systems in the maritime domain. Prior permission was requested from VikingLine and the crew of the vessel to conduct a few tests using communication, navigation and positioning equipment in addition to observations of the Integrated Bridge System (IBS), interviews with the crew and data recording from vessel's own electronic systems.

The nature and contents of the test campaign are listed below:

- To study the IBS technology and to observe the interaction between the crew and the IBS components.
- To analyze the data recorded by the crew from the IBS PilotPlug.
- To study the performance of our FGI-GSRx navigation receiver assembly on the open sea.
- To make measurements related to performance and coverage of various communication technologies such as mobile wireless (3G/4G), wide-area broadband networks, satellite-based communication, Digital Video Broadcast (DVB), FM radio stations etc. on the open sea.
- To study the navigation signals received from the Finnish Geodetic Reference System (FinnRef) stations on Ahvenanmaa and the coast of Western Finland.
- To record performance of motion (and other) sensors.

In view of the considerable stress experienced by the crew during the voyage the following precautions were taken during the test-campaign:

- Specially installed antenna(s) were to be receive-only. Test equipment would not transmit any wireless signals.
- The test electronic systems would function independently of the ship systems and networks.
- Test electronic equipment would not be connected to the ship systems in a way other than receive-only mode.
- There would be no interference with the crew operations, especially in the critical periods of port-exit and entry.

The results were expected to enhance the integrity of the research. They will enable distillation of the most critical information for crowdsourcing in the maritime scenario, and also help to determine the feasibility of providing the proposed ESABALT services in the Finnish/Swedish archipelago.

The test data is currently under analysis and its results will be described in more detail in the ESABALT BONUS Progress Report 1.

11 Conclusion

This document describes the work performed during the ESABALT Work package 3: State of the Art Analysis and Technology Evaluation. It contains the initial findings and background about technologies, procedures, regulations, techniques and previous projects and commercial products developed in the domain of maritime safety of transportation and situational awareness at sea.

This WP has been divided into seven tasks distributed among the partners based on their background and skill-set: review of the maritime safety approaches, analysis of navigation technologies, evaluation of Earth Observation technologies, communication technologies evaluation, evaluation of AIS sensors, evaluation of other existing user-driven solutions for enhancing transportation safety and situational awareness and their applicability to the maritime environment, and feasibility of the crowdsourcing approach for marine information gathering.

The background research was performed in a manner that enabled each assigned partner the freedom to research the subject matter independently and according to its own desired techniques and style. The objective was to ensure that research and analysis would be as broad as possible at this stage in the project, so that applicable technologies, ideas, and best practices may then be filtered and adapted for the unique requirements of the ESABALT project implementation.

In conclusion, it was observed that there are a number of solutions to specific problems in the maritime domain, especially to enhance safety at sea. However, there is a definite gap in the availability of a common software platform which will aggregate maritime information obtained from crowdsourcing (information provided manually by humans or automatically by vessels) and provide thus a cross-sector, cross-border overview of the current situation of the traffic, environment, and weather in the Baltic Sea. Therefore, this WP has allowed ESABALT to identify a niche for itself, where it can contribute to the overall maritime situational awareness in the Baltic Sea.

12 References

IALA, IALA Technical clarifications on recommendation ITU-R M. 1371-3, edition 2.4. 2009.

IALA, IALA Guidelines on the universal automatic identification system (AIS),Volume 1, Part I – Operational Issues 1028, Edition 1.3, 2002, revised 2004.

IALA, IALA Guidelines on the universal automatic identification system (AIS),Volume 1, Part II – Technical Issues 1029, Edition 1.1, 2002.

IALA, IALA Recommendation A-126 On The Use of the Automatic Identification System (AIS) in Marine Aids to Navigation Services Edition 1.5, 2011.

IMO Circular SN/227 – Guidelines for the installation of a shipborne Automatic Identification Systems (AIS), 2003.

IMO Resolution A.917(22) – Guidelines for the onboard operational use of shipborne Automatic Identification Systems (AIS), 2002.

IMO Resolution A.956(23) – Amendments to the Guidelines for the onboard operational use of shipborne Automatic Identification Systems (AIS), Resolution A.917(22), 2004.

Ali, K., Al-Yaseen, D., Ejaz, A., Javed, T., Hassanein, H.S. (2012). CrowdITS: Crowdsourcing in intelligent transportation systems. In Proceedings of IEEE Wireless Communications and Networking Conference.

Aubry, E., Silverston, T., Lahmadi, A., Festor, O. (2014) CrowdOut: A mobile crowdsourcing service for road safety in digital cities. In Proceedings of PERCOM Workshops, 24-28 March, Budapest, Hungary, IEEE, pp. 86 – 91.

Bregman, S. (2012). TCRP Synthesis 99: Uses of Social Media in Public Transportation. Washington, DC: Transportation Research Board

Chilton A., Mason, B. Can you trust the maritime crowd? July/August 2013, 50-51, available at: http://www.geoconnexion.com/uploads/publication_pdfs/MaritimeCrowd_ukv11i4.pdf, accessed 09.03.2015

Econom, a blog, available at: http://blog.econocom.com/en/blog/crowdsourcing-new-management-model, accessed 16.1.2015

FIlippi, F., Fusco, G. and Nanni, U. (2013). User Empowerment and Advanced Public Transport Solutions. Procedia - Social and Behavioral Sciences, Volume 87, 3-17

Franzoni C., Sauermann H. (2014). Crowd science: the organization of scientific research in open collaborative projects. Research Policy, Vol. 14, pp. 1-20.

Gao, H. Barbier, G., Goolsby, R. (2011). Harnessing the Crowdsourcing Power of Social Media for Disaster Relief. IEEE Intelligent Systems, May/June 2011, 10-14.

Golledge, R., 1995, Defining the criteria used in path selection, Technical Report UCTC No. 78, University of California Transportation Center.

Gorin, A., Caouissin, M., Guichon, D., Delache, X. (2014). A probabilistic approach for data quality assessment of road hazard warnings in crowdsourced driving navigation systems. In Proceedings of Transport Research Arena, Paris, France.

Greencitystreets (2013). http://www.greencitystreets.com/busmeister.

Klettner, S., Huang, H., Schmidt, M., Gartner, G. (2013): Crowdsourcing affective responses to space. KN Kartographische Nachrichten - Journal of Cartography and Geographic Information, no.2.

Marjanovic S., Fry, C., and Chataway, J. (2012). Crowdsourcing based business models: In search of evidence for innovation 2.0. Science and Public Policy, 39, 318–332

MARSUNO (2011). Final report. Available at: http://www.marsuno.eu/index-8.html, accessed 18.12.2014.

Moovit available at: http://www.moovitapp.com/how-it-works/, accessed 10.12.2014.

Van Norden M., Cooper P., Hersey J. (2013). Crowdsourced Bathymetry, One Solution for Addressing Nautical Chart Data Deficiencies. Proceedings of US Hydro 2013, March 25-28, New Orleans, LA.

Nunes, A. A., Galvão, T., Falcão, Cunha, J., & Pitt, J. (2011). Using social networks for exchanging valuable real time public transport information among travellers. Proceedings of the 2011 IEEE 13th Conference on Commerce and Enterprise Computing, 365–370.

Omokaro, O., Payton, J. (2014). FlySensing: A case for Crowdsensing in the Air. In Proceedings of IEEE Workshop on Pervasive Collaboration and Social Networking, 545-550.

OpenSeaMap, available at: http://www.openseamap.org/index.php?id=faq&L=1, accessed 16.1.2015.

OpenStreetMap, available at: http://www.openstreetmap.org/#map=5/51.500/-0.100, accessed 16.1.2015.

Reid T., Walter T., Enge P., Fowler A.(2014). Crowdsourcing Arctic Navigation Using Multispectral Ice Classification. Proceeding of ION GNSS, September 8-12, Tampa, FL, pp. 707-721.

Vedel T., Hansen H. (2012). Webgis based crowdsourcing, aiming at producing inland lake charts in Denmark, available at: http://projekter.aau.dk/projekter/files/61138241/WebGis_VGI_Thomas_Vedel_GTM10.pdf, accessed 09.03.2015

van der Wees, B.J. (2011). The potential of in-train crowdsourcing. In Proceedings of 14thTwente Student Conference on IT, January 21st, Enschede, The Netherlands.

Zambonelli, F. (2011). Pervasive Urban Crowdsourcing: Visions and Challenges. In Proceedings of PERCOM Workshops, 21-25 March, Seattle, VA, pp. 578 – 583, IEEE.

Zimmerman, J., Tomasic, A., Garrod, C., Yoo, D., Hiruncharoenvate, C., Aziz, R., Thiruvengadam, N.,R., Huang, Y., & Steinfeld, A. (2011). Field Trial of Tiramisu: Crowd-Sourcing Bus Arrival Times to Spur Co-Design. Proceedings of the ACM International Conference on Human Factors in Computing Systems, CHI 2011, Vancouver, BC, Canada, May 7-12, 2011. New York: Association for Computing Machinery.

Choi M. S., Kim B., Kim K. H., Jeong M.A., Lee S. R., "Ship to Ship Maritime Communication for e-Navigation Using IEEE 802.16j", Advanced Science and Technology Letters, Vol.28 (CIA 2013), pp.110-115.

Yun N., Park T., Jung K., Jang B. T., Lim D. S., Kim J. M., “Simulation Analysis on BER Patterns Based Maritime Ad-hoc Networks, Future Information Technology, Application, and Service”, Lecture Notes in Electrical Engineering, Vol. 164, pp. 629-635 (2012).

“Unit 7: Marine Communications Technology”, available at: http://www.ed.gov.nl.ca/edu/k12/curriculum/guides/teched/commtech2104/ct2104_unit7.pdf, accessed 09.03.2015

Jakovlev S., Voznak M., Andziulis A., Kurmis M., "Communication Technologies for the Improvement of Marine Transportation Operations", 12th IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems August 11-15, 2013. Las Vegas, NV, USA.

Bradbury D., "Maritime ICT: a new wave of technology", Engineering and Technology Magazine, 17 June 2013, available at: http://eandt.theiet.org/magazine/2013/06/a-new-wave-of-technology.cfm, accessed 09.03.2015

Rødseth Ø. J., "Communication between ship and shore", Maritime Information Technology standards, August 2012, available at: http://www.mits-forum.org/communication.html, accessed 09.03.2015

Rødseth Ø. J., Kvamstad B., "The role of communication technology in e-Navigation", MARINTEK Report MT28 F09-095, 5th March 2009.

Rødseth Ø.J., Graziosi N., Nicolè R., "Research report on broadband applications - Part1: State of the art", MarNIS Deliverable D2.2.C-1, 3rd July 2006.

Norphonic, "Maritime VoIP Communications for Oil & Gas, Ships and Offshore Facilities", available at: http://www.norphonic.no/web/applications/maritime-voip-communications-for-oil-a-gas-ships-and-offshore-facilities.html, accessed 09.03.2015

"Maritime Communication Systems (MCS)", Frequentis, available at: http://www.frequentis.com/fr/uk/solutions-portfolio/maritime/products-and-solutions/maritime-communication-systems-mcs/, accessed 09.03.2015

Nicholls C., "Upgrades enable latest GSM technology for shore contact", Globe Wireless, Marine Electronics & Communications, April/May 2012, available at: http://www.globewireless.com/files/MEC_Apr_2012.pdf, accessed 09.03.2015

"Globe Wireless and INMARSAT", available at: http://www.globewireless.com/, accessed 09.03.2015

"EfficienSea", available at: http://www.efficiensea.org/default.asp, accessed 09.03.2015

"AIS+", Available at: http://www.aisplus.vtt.fi/index.html, accessed 09.03.2015

Chang S., Yen C., Chiu Y., Chang F., "Cluster-based spatial planning and evaluation of maritime mesh network using vessel traffic data", 12th International Conference on ITS Telecommunications (ITST), Nov. 2012, Taipei, Taiwan.

Zhou M., Hoang V. D., Harada H., Pathmasuntharam J. S., Haiguang W., Kong P., Ang C., Ge Y., Wen S., "TRITON: high-speed maritime wireless mesh network", IEEE Journal on Wireless Communications, Vol:20, Issue: 5, pp: 134 - 142 , October 2013.

Boreli R., Yu G., Iyer T., Dwertmann C., Pathmasuntharam J. S., "Intelligent Middleware for High Speed Maritime Mesh Networks with Satellite Communications", Proceedings of the 9th International Conference on Intelligent Transport Systems Telecommunications, (ITST), 2009, France

iN.SG, "WISEPORT garners strong support from maritime industry", available at: http://www.ida.gov.sg/blog/insg/egov-sectors/wiseport-garners-strong-support-from-maritime-industry/, accessed 09.03.2015

"WiredOcean", available at: http://www.wiredocean.com/index.html, accessed 09.03.2015

Askne, J., Dierking, W., 2008. Sea ice monitoring in the Arctic and Baltic Sea using SAR, in: Remote Sensing of the European Seas. Springer, pp. 383–398.

Brekke, C., Solberg, A.H.S., 2005. Oil spill detection by satellite remote sensing. Remote Sens. Environ. 95, 1–13. doi:10.1016/j.rse.2004.11.015

CEOS (Committee on Earth Observation Satellites), 2015. The Earth Observation Handbook [WWW Document], available at: http://eohandbook.com/, accessed 05.03.2015

CleanSeaNet 2014. available at: http://emsa.europa.eu/operations/cleanseanet.html, accessed 27.06.2014

Dolphin, 2014. available at: www.gmes-dolphin.eu, accessed 27.06.2014

ESA (European Space Agency), 2015. Earth Observation Portal, available at: https://directory.eoportal.org/web/eoportal/satellite-missions, accessed 05.03.15

Ferraro, G., Baschek, B., de Montpellier, G., Njoten, O., Perkovic, M., Vespe, M., 2010. On the SAR derived alert in the detection of oil spills according to the analysis of the EGEMP. Mar. Pollut. Bull. 60, 91–102. doi:10.1016/j.marpolbul.2009.08.025

Fingas, M., Brown, C., 2014. Review of oil spill remote sensing. Mar. Pollut. Bull. doi:10.1016/j.marpolbul.2014.03.059

Greidanus, H., 2008. Satellite imaging for maritime surveillance of the European seas, in: Remote Sensing of the European Seas. Springer, pp. 343–358.

Gruner, K., Reuter, R., Smid, H., 1991. A new sensor system for airborne measurements of maritime pollution and of hydrographic parameters. GeoJournal 24, 103–117. doi:10.1007/BF00213062

Klemas, V., 2011. Remote Sensing of Sea Surface Salinity: An Overview with Case Studies. J. Coast. Res. 276, 830–838. doi:10.2112/JCOASTRES-D-11-00060.1

Kramer, H.J., 2002. Observation of the Earth and its Environment: Survey of Missions and Sensors. Springer.

Kongsberg Satellite Services, KSAT. available at: www.ksat.no, accessed 27.06.2014

Langille, A.K., Buckley, J.R., 2002. Estimation of sea surface temperature using passive microwave satellite imagery, in: Geoscience and Remote Sensing Symposium, 2002. IGARSS'02. 2002 IEEE International. pp. 2141–2143.

Leifer, I., Lehr, W.J., Simecek-Beatty, D., Bradley, E., Clark, R., Dennison, P., Hu, Y., Matheson, S., Jones, C.E., Holt, B., Reif, M., Roberts, D. a., Svejkovsky, J., Swayze, G., Wozencraft, J., 2012. State of the art satellite and airborne marine oil spill remote sensing: Application to the BP Deepwater Horizon oil spill. Remote Sens. Environ. 124, 185–209. doi:10.1016/j.rse.2012.03.024

MAIRES, 2011. available at: www.nersc.no/project/maires, accessed 27.06.2014.

Martin, S., 2013. An Introduction to Ocean Remote Sensing. Cambridge University Press, Cambridge. doi:10.1017/CBO9781139094368

Miller, R.L., Castillo, C.E. Del, Mckee, B.A., 2007. Remote Sensing of Coastal Aquatic Environments, Remote Sensing and Digital Image Processing. Springer Netherlands, Dordrecht. doi:10.1007/978-1-4020-3100-7

MyOcean, 2014. available at: http://www.myocean.eu, accessed 27.06.2014.

MyWave, 2014. available at: www.mywave.eu, accessed 27.06.2014.

NEREIDS, 2014. available at: http://maritimesurveillance.security-copernicus.eu/fp7-supporting-projects/nereids, accessed 27.06.2014.

SAGRES, 2014. available at: http://www.copernicus.eu/pages-principales/projects/other-gmes-projects/security/, accessed 24.06.14.

Salberg, A., 2013. Multisource oil spill detection. SPIE Remote … 8892, 88920W. doi:10.1117/12.2029208

Sandven, S., 2008. Sea Ice Monitoring in the European Arctic Seas Using a Multi-Sensor Approach, in: Remote Sensing of the European Seas. Springer, pp. 487–498.

Teleti, P.R., Luis, A.J., 2013. Sea Ice Observations in Polar Regions : Evolution of Technologies in Remote Sensing 2013, 1031–1050.

Tsui, O.W.; Coops, N.C.; Wulder, M.A.; Marshall, P.L. Integrating airborne LiDAR and space-borne radar via multivariate kriging to estimate above-ground biomass. *Remote Sens. Environ.* 2013, *139*, 340–352.

Zwally, H.J., B. Schutz, W. Abdalati, et al. 2002. ICESat's Laser Measurements of Polar Ice, Atmosphere, Ocean, and Land. *Journal of Geodynamics* 34(3-4): 405-445.

Seapilot, available at: https://www.seapilot.com/, accessed 09.03.2015

Navionics, available at: http://www.navionics.com/, accessed 09.03.2015

ARIADNA, available at: http://ariadna-fp7.eu/, accessed 09.03.2015

Baltic Master I, available at: http://www.balticmaster.org/general.aspx?page_id=3, accessed 09.03.2015

Baltic Master II, available at: http://www.balticmaster.org/general.aspx?page_id=3, accessed 09.03.2015

COSINUS, available at: http://www.offis.de/en/r_d_divisions/transportation/project/projekte/cosinus.html, accessed 09.03.2015(a)

COSINUS, available at: http://www.emaritime.de/projects/cosinus/, accessed 09.03.2015(b)

EMAR, available at: http://www.emarproject.eu/, accessed 09.03.2015

MarNIS, available at: http://www.transport-research.info/web/projects/project_details.cfm?id=11127, accessed 09.03.2015

MONALISA, available at: http://www.sjofartsverket.se/en/MonaLisa/, accessed 09.03.2015

MONALISA 2.0, available at: http://www.sjofartsverket.se/en/MonaLisa/, accessed 09.03.2015

MUNIN, available at: http://www.unmanned-ship.org/munin/, accessed 09.03.2015

NAVTRONIC, available at: http://www.transport-research.info/web/projects/project_details.cfm?id=39065, accessed 09.03.2015

SAFEWIN, available at: http://www.safewin.org/, accessed 09.03.2015

TRITON, available at: http://tritonproject.eu, accessed 09.03.2015

ASSET, available at: http://www.project-asset.com/index1.php?lan=en, accessed 09.03.2015

EFFORTS, available at: http://ec.europa.eu/research/transport/projects/items/efforts_en.htm

MASAS-X, available at: https://www.masas-x.ca/en/, accessed 09.03.2015

SAFIRE, available at: http://cert.ics.uci.edu/SAFIRE/index.html, accessed 09.03.2015

NICTA, available at: https://www.nicta.com.au/research/completed_projects/situation_awareness_by_inference_and_logic, accessed 09.03.2015

MARCOM, available at: http://www.sintef.no/upload/MARINTEK/Projects/MarSafe/ESA_MarCom_enav.pdf, accessed 09.03.2015

TESSA, available at: http://www.cmcc.it/projects/tessa-development-of-technologies-for-the-situational-sea-awareness , accessed 09.03.2015

SMOS, available at: http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS, accessed 09.03.2015

Weintrit A., The Electronic Chart Display and Information System (ECDIS), An Operational Handbook, CRC Press 2009

IMO, SOLAS Ch V – Regulations, Annex 17 - Automatic Identification Systems (AIS), Regulation 19.2.4

INO, Automatic Identification System, available at: http://www.imo.org/OurWork/Safety/Navigation/Pages/AIS.aspx, accessed 09.03.2015

Banachowicz A., Wolski A., "The fusion of coordinates of ship position and chart features," in Advances in Marine Navigation – Marine Navigation and Safety of Sea Transportation, A. Weintrit, Ed. London, UK: Taylor & Francis Group, 2013, pp. 57–60.

Fairbanks M., Basker S., Ventura-Traveset J., de Mateo J.C., "EGNOS Performance for Maritime Users," 2000, available at: http://www.egnos-pro.esa.int/Publications/GNSS%202000/gnss2000_MAR.pdf, accessed 09.03.2015

Gibbons G., "GLONASS Suffers Temporary Systemwide Outage; Multi-GNSS Receiver Overcomes Problem," InsideGNSS, April 2, 2014, available at: http://www.insidegnss.com/node/3979, accessed 09.03.2015

"ECDIS - What you need to know," Jeppesen Marine, 2011, available at: http://ww1.jeppesen.com/documents/marine/commercial/brochures/ECDIS_booklet.pdf, accessed 09.03.2015

Bosch W., Bärlocher M., "OpenSeaMap – Wassertiefen per Crowdsourcing," Hydrographische Nachrichten, June 2013 (in German).

Heymann F., Banys P., Noack T., Engler E., "Is ARPA Suitable for Automatic Assessment of AIS Targets?", in Advances in Marine Navigation – Marine Navigation and Safety of Sea Transportation, 2013, Weintrit A. (eds), pp. 223-232, CRC Press,