Operational Scenarios for Maritime Safety in the Baltic Sea

Kuusniemi H. [1], Thombre S. [1], Söderholm S. [1], Chen L. [1], Guinness R. [1], Pietrzykowski Z.[2], Wołejsza P.[2]
[1] *Finnish Geospatial Research Institute, National Land Survey of Finland*
[2] *Maritime University of Szczecin, Poland*

BIOGRAPHY

Prof. Heidi Kuusniemi is the Director and Professor at the Department of Navigation and Positioning at the Finnish Geospatial Research Institute (FGI). She is also an Adjunct Professor at Aalto University and Tampere University of Technology, Finland. She is the President of the Nordic Institute of Navigation, and the Conference Chair for the 2016 European Navigation Conference (ENC 2016) in Helsinki, Finland. She received her M.Sc. and doctor of technology degrees from Tampere University of Technology, Tampere, Finland. Kuusniemi's research interests cover various aspects of GNSS and sensor fusion for seamless outdoor/indoor positioning.

Dr. Sarang Thombre is a Senior Research Scientist and Deputy Leader of the Intelligent Mobility and Geospatial Computing research group at the Department of Navigation and Positioning of the Finnish Geospatial Research Institute. He received his M.Sc. and D.Sc. (Tech.) degrees from Tampere University of Technology, Finland. He is currently the Technical Project Manager for the EUSBSR Flagship Project *BONUS ESABALT*, and a member of the board of the Nordic Institute of Navigation. His research interests include innovations in GNSS receiver implementation, system design, and algorithm implementation for maritime safety and ice-aware navigation.

Mr. Stefan Söderholm is a Researcher at the Finnish Geospatial Research Institute, Department of Navigation and Positioning. He is working on improving the performance in consumer grade GNSS receivers. From 2004 he headed the Fastrax software development team, and 2008 he became Vice-President of R&D in the company. Söderholm has worked as a Project Manager in the algorithm and signal processing team at u-blox. He received his M.Sc. degree from Åbo Akademi University in and his Licentiate degree from University of Turku.

Dr. Liang Chen is a Senior Research Scientist in the Department of Navigation and Positioning at the Finnish Geospatial Research Institute (FGI), Finland. In addition, he is also an Adjunct Professor in Jiangsu University, China. He received his PhD in Signal and Information Processing from Southeast University, China, in 2009 and his M.Sc in Control Theory and Control Engineering from Jiangsu University, China in 2004. His research interests include statistical signal processing for positioning, wireless positioning using signals of opportunity and sensor fusion algorithm for indoor positioning.

Mr. Robert E. Guinness is a Senior Research Scientist in the Dept. of Navigation and Positioning at the Finnish Geospatial Research Institute (FGI) of the National Land Survey of Finland. He is also a doctoral candidate at Tampere University of Technology, Finland, and co-author of the book Geospatial Computing in Mobile Devices, published by Artech House in 2014.

Prof. Zbigniew Pietrzykowski is a Professor and Deputy Dean for Science at the Faculty of Navigation of the Maritime University of Szczecin, Poland. He is also a member of the Section Traffic Control in Transport, Transport Committee, Polish Academy of Science, the Polish Safety and Reliability Association, the Polish Association of Transport Telematics and the Polish Navigation Forum (Polish Institute of Navigation). His research interests include intelligent transport systems, decision support systems, and navigation.

Dr. Piotr Wołejsza is a Master Mariner and navigation officer with 15 years of practice at sea. Since 2013 he is a full time employee in the Institute of Geoinformatics at the Maritime University of Szczecin, Poland. His research interests include navigation, decision support and intelligent transport systems.

ABSTRACT

The project *Enhanced Situational Awareness to Improve Maritime Safety in the Baltic (BONUS ESABALT)* is a research and development project funded by the BONUS program for studying the feasibility of a novel system for enhancing maritime safety, focusing on the Baltic Sea as a test-bed for the system and service concept. In this paper, we describe the system architecture for the proposed ESABALT concept. Next, we describe few maritime scenarios in which the proposed system can be beneficial. These scenarios can be grouped under three specialized services of intelligent marine navigation and routing information, efficient emergency response, and environmental monitoring and reporting with emphasis on cross-border cross-sector functionality. The paper also summarizes the test and maritime data collection campaign performed onboard the Viking Line's cruise

ship 'Amorella', operating on the Turku – Stockholm – Turku route. The aim of this exercise was to collect data generated by the ship's own electronic systems, and also to determine the availability and performance of navigation and communication signals along the maritime route. Analysis of this data is expected to enable distillation of the most critical information for crowdsourcing in the maritime scenario. Finally, we discuss the expected societal and economic impact of the proposed system in the Baltic Sea Region maritime domain.

INTRODUCTION

In 2010 the European Union launched a new research and development program to protect the Baltic Sea, called the Baltic Organizations Network for Funding Sciences EEIG (BONUS). BONUS [1] is considered as the first model case for the development of science-based management of the European regional seas by bringing together the research communities of marine, maritime, economical and societal research to address the major challenges faced by the Baltic Sea region.

The project *Enhanced Situational Awareness to Improve Maritime Safety in the Baltic (BONUS ESABALT)* [2] is a research and development project funded by the BONUS program for studying the feasibility and implementing a proof-of-concept demonstrator of a real-time integrated software-based mechanism offering user-driven information services for optimal decision-making towards the marine environment, safety and security in the Baltic Sea area. In 2015, ESABALT was awarded the status of Flagship Project under the EU Strategy for Baltic Sea Region's Policy Area on Maritime Safety and Security (PA SAFE). The partners in the ESABALT consortium include the Finnish Geospatial Research Institute (FGI), Furuno Finland Ltd, SSPA Sweden, and Maritime University of Szczecin (MUS), Poland.

The primary goal of ESABALT is to study the feasibility of implementing a software platform for maritime situational awareness through vessel-driven and user-driven autonomous information crowdsourcing techniques in order to enable cross-border cross-sector cooperation, and therefore enhanced maritime safety, security, environmental monitoring and emergency response in the entire Baltic Sea region. ESABALT aims to integrate latest technological advances in sensing, positioning, e-Navigation, Earth observation systems, and multi-channel cooperative communications. Three specialized services will be studied: intelligent marine navigation and routing information, efficient emergency response, and environmental monitoring and reporting with emphasis on cross-border cross-sector functionality.

ESABALT will differ from traditional navigation information systems, as it learns from users' navigation experiences to provide dynamic, intelligent (ice-aware, environment-aware, and accident-aware) and energy-efficient route plans, and efficient emergency response. Information can be exchanged between commercial vessels, pleasure boats, authorities and distributed sensor stations instantly, making all of them stakeholders in the improvement of the overall Baltic Sea maritime situational awareness. For more information on the concept, potential users, system requirements and functional description of the proposed ESABALT system please refer to [3], [4], [5], and [6].

Section 1 of this paper describes the gaps in current maritime technology which provide the motivation behind the development of the ESABALT concept. Section 2 includes a short description of a test and data collection campaign performed onboard Viking Line's cruise ship 'Amorella', plying the Turku – Stockholm – Turku route. Section 3 presents few example scenarios to describe the functionality of the proposed system. Section 4 describes briefly the ESABALT system architecture. The paper concludes in Section 5 with a discussion on the expected impact of the system in the societal and economic domains in the Baltic Sea Region.

WHAT IS THE NEED FOR THE ESABALT SYSTEM?

During the formative stages of the project, the proposed concept was validated by reaching out to the maritime community—the potential users of the ESABALT system—through an online survey to gauge the need and willingness to adopt such a system, as well as to gather general feedback on the operational needs and constraints of maritime stakeholders. The survey received over 160 responses from over 20 countries. The results of the user survey generally validated the overall ESABALT concept, i.e. such a system would indeed contribute to improved maritime safety and that mariners would be willing to participate in the crowdsourcing aspects if they were provided the technical capability.

Simultaneously, a user needs study was conducted as part of the project *VORIC (Vessel Operations and Routing in Ice Conditions)* [7], to capture the needs of key stakeholders in the project. The focus was on the gaps – what (information) services should be developed further to get the highest benefits from a user perspective in the domain of vessel operations and routing in ice conditions. Industry experts from maritime operations, safety, traffic and ice-navigation participated in the interview-format survey. The key takeaways were that a software platform for real-time dissemination of (1) sea, ice and weather conditions, (2) successful traversed routes through ice, and (3) human observations, was missing. Ice-breakers that service ice-bound routes do not necessarily have the time to reply to individual queries about the prevailing conditions. Therefore, autonomous information generation and dissemination is necessary, which will help reduce the burden on the crew to respond.

(a) Ship cannot locate the broken route in low visibility.

(b) Ice-breaker radar track shows the route it took through the ice.

(c) Based on this radar track shared by the ice-breaker, the vessel is able to re-orienteer to the broken route.

Fig. 1 Benefits of information crowdsourcing in ice-navigation.

For example, periodic and automated monitoring and dissemination of engine power coupled with weather data gathered by the ice-breaker would provide valuable estimates about the ice-thickness to other ships planning to take the same route. Furthermore, in the Baltic Sea many ice-strengthened vessels can themselves break a path through fresh ice on their own engine power. Through the ESABALT concept these vessels can henceforth also contribute to data crowdsourcing, thus helping to broaden and diversify the sources of situational information. Another possibility is to aid a ship in a convoy during low visibility (e.g. during a snow-storm in the night) to accurately locate the path broken by the leading ice-breaker by disseminating successfully traversed routes in the form of aggregated AIS (Automatic Information System) tracks, webcam images, and/or ice-radar tracks. Figs. 1(a), 1(b) and 1(c) describe this scenario pictorially. Additional information on gaps in state-of-art situational awareness processes was identified during interviews with the crew of the Viking Line ‘Amorella’, as described in the next Section.

(It should be noted that the gaps in technology are different in the Baltic Sea and the Arctic region [15]. The technology is well developed in the Baltic Sea, however there is still scope for improvement through the use of automation. The greater need for radical technological innovation is in the Arctic region).

TEST AND DATA COLLECTION CAMPAIGN ONBOARD VIKING LINE ‘AMORELLA’

The aim of this test campaign was to interview the navigators operating the ship’s integrated bridge system (IBS) about their views on the current gaps in maritime information systems, and to collect data generated by the ship’s own electronic systems, and finally to determine the availability and performance of navigation and communication signals along the maritime route. Over the course of three days, data from the ship’s Differential GPS and AIS systems, engine room sensors, navigation satellites, the Finnish Reference GNSS network (FinnRef), local FM, Digital TV (DTV), 3G and LTE (Long Term Evolution) stations was collected. Here, we also present first results of the collected data analysis, which will be beneficial for distillation of the most critical information for crowdsourcing in the maritime scenario.

Findings from Interviews with the Ship’s Crew: These interviews revealed opinions of ship navigators about the challenges faced in their day-to-day activities and also some suggestions on mitigating them.

- During the ice-free seasons the Baltic Sea can be overcrowded with small boats (motorized pleasure craft, sail boats etc.). Together, their AIS strings overload the electronic charts (ECDIS) display. Furthermore, small boats pose accident risks if they accidently cross in the navigable channel of big vessels. As not all small boats carry a VHF (very high frequency) radio, communicating with them is a challenge. A mechanism to send quick,

automated, predefined and short messages between large vessels and small boats will be beneficial.
- In case of emergency, the established process is to initiate a distress call wherein the ship's information (current position, nature and severity level of the emergency, number of persons on board, etc.) is autonomously embedded. This distress signal is received by all ships in the vicinity and also by the authorities. Vessel Traffic Services (VTS) takes command of the situation and search and rescue is initiated. Sailors traversing the Baltic Sea regularly are familiar with each other and hence, other vessels may aid in the rescue. Although for large vessels, changing course is not always feasible. Integrating pleasure boats in the incident reporting, search and rescue processes will be beneficial.
- VTS provides updates about potential hazards such as drift ice or loose buoys. However, real time information about weather and sea conditions to be expected few kilometers ahead in the fairway or narrow archipelago would be beneficial to determine route plans. Such information can be obtained autonomously either from deployable sensors or other ships which have already passed through the fairway.
- Similarly, in port areas aerial views of the current traffic situation can be beneficial.
- In adverse weather or visibility conditions radar is sufficient for safe navigation, although presence of strong waves can pose a significant challenge. In such conditions information from planned routes of other ships may have some value. However, additional temporary and/or virtual aids-to-navigation (A-to-N) are more beneficial.
- It is worth investigating if and how other solutions involving using synthetic aperture radar cameras, thermal imaging cameras, oil & ice radars can beneficial.
- While data crowdsourcing can be beneficial, proper attention must be paid to maintaining anonymity of the source and to avoiding information overload on the crew. Also, the new system should not attempt to compete with and replace existing systems, rather should function seamlessly and in collaboration with them.

These end-user opinions were instrumental in developing some of the functional description and operational scenarios of the ESABALT concept, as described in the next Section.

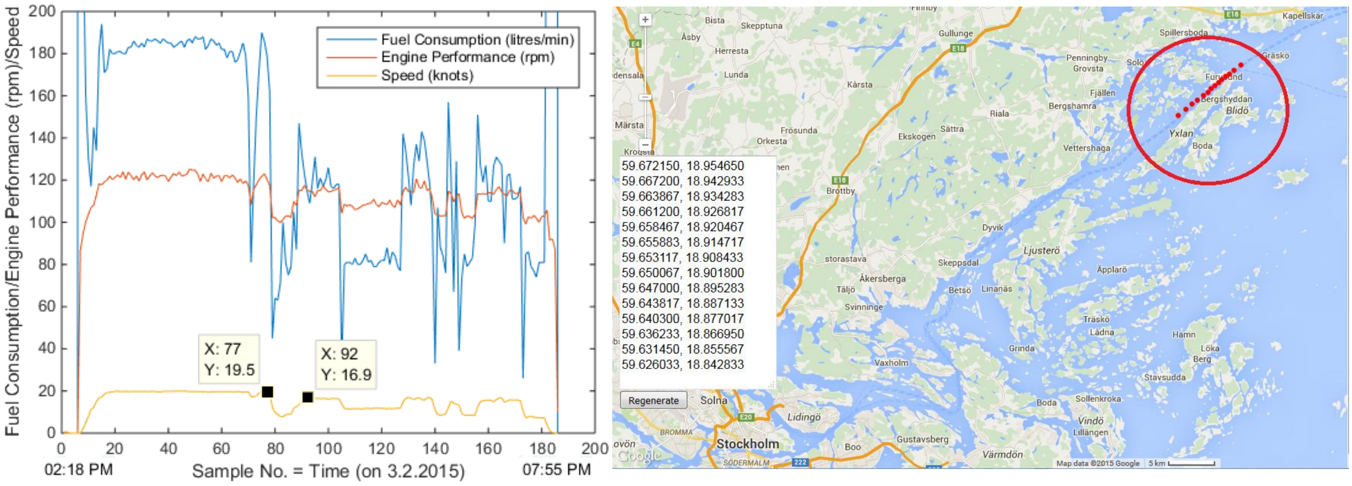
Information from IBS Pilot Plug: Data from the vessel's Integrated Bridge System pilot plug was recorded over the entire return journey between Stockholm and Turku, starting from 2nd February at 20:55 until 06:30 on 3rd February. A pilot plug – to – USB cable [8] was used to record the data in text format direct to a laptop. The total size of the record file was 21.4 MB. Pilot-Plug provides data in sentences, each starting with an introducer for identification of the data contained in the sentence. !AIVDM and !AIVDO sentences are created by the Automatic Identification System (AIS). !AIVDM sentences are reports from other ships and !AIVDO sentences are reports from own ship [9]. $PSTT introducers are reserved for proprietary sentences, while $AIALR denote alarm messages.

The sentences in the text file can be decoded, for example using the AIS Decoder tool [10]. The decoded data consists of the following information:
- details of own ship (identifier, position, speed, etc.),
- details of other ships in the vicinity,
- alarm messages describing anomalies in the positioning or communication systems of own ship,
- other error messages, especially in the received data formats.

The AIS information about vessel positions can be replayed using the NAVISIMU simulator and marine pc with ESABALT Furuno FFSC-200 software from Furuno Finland Ltd. This information along with the alert messages is therefore useful for simulating live scenarios at sea in order to validate the ESABALT concept.

Information from Engine Room, Bridge, and Hull Sensors: The engine room sensors record at regular intervals data about the vessel's engine performance. Simultaneously, information about the ship's situational environment is also recorded from the bridge and hull sensors. In our campaign the data was recorded to a text file (size 21 KB) approximately once every two minutes between 14:00 and 20:00 on 3rd February, 2015. Useful contents of the data are listed here.
- fuel consumption (in liters/minute),
- speed (in knots),
- revolutions per minute (rpm) of the port and starboard propellers,
- absolute wind speed (meters/sec) and direction of origin (in degrees),
- ship's compass reading (in degrees) showing the heading,
- ship's clearance (in meters),
- position of the ship in latitude and longitude,
- draft, fore and aft (in meters),
- date and time stamp of each information record.

In Fig. 2(a) the fuel consumption, engine performance and speed are plotted with respect to time in order to show the data correlation between these quantities. It can be observed that between data sample numbers 77 (4:36 pm) and 92 (5:00 pm), the ship reduced its speed considerably. If we plot the progressive position of the ship as it moved during this time interval (Fig. 2(b)) we notice that it was traversing one of the narrowest portions of the Stockholm archipelago. If this information was shared with other ships intending to traverse a similar route soon afterwards, it would help in intelligent fore-planning of the speed along the route through the archipelago. This benefit is especially pronounced during operations in sea-ice. This is because observing the real-time speed (or engine power) of a ship few kilometers ahead can be indicative of the expected ice conditions along the upcoming route.



(a) (b)

Fig. 2 Vessel data from engine room may be indicative of the surrounding geospatial or weather situation.

The challenge in autonomous data sharing is to implement data analysis algorithms which will extract actionable information from the crowdsourced data. A design choice is also needed as to the appropriate place where these algorithms should be implemented – at the source, in the data server, or in ships where it will be utilized.

Information from Additional Sensors: Situational awareness about weather and sea conditions (for example, wave height) is crucial for maintaining safety of maritime transport. The Finnish Meteorological Institute (FMI) disseminates the current and forecasted wave height information for the Baltic Sea [12]. However, such information is based on only few deployable sensor stations in the Northern Baltic Sea. The resolution and accuracy of the information can be improved if vessels traversing the Baltic Sea can host sensors which would sense the local wave conditions based on the real-time pitch variations of the ship, and then contribute this information to ESABALT forming a collaborative image of sea wave conditions over wide area of the Baltic Sea.
During the voyage an Xsens MTi-G-700 [11] motion sensor was installed in the test environment for recording the real-time motion of the vessel due to sea-waves. The MTi-G-700 Global Positioning System (GPS)/Inertial Navigation System (INS) is a GPS-aided, inertial measurement unit (IMU)-enhanced GPS/INS that offers high-quality orientation and position. Data was collected at various points during the voyage. Fig. 3 shows the real-time variations in the pitch as recorded by the sensor at 16:50 on 2nd February, 2015, with approximate location being at the mouth of the Stockholm archipelago. Assuming for simplicity that the vessel (length 169 m) experiences only one degree of freedom due to the sea waves, the pitch values from Fig. 3 indicate approximately 0.2-0.5 meters of wave height. These figures are expected in this area during the winter season, as shown in [13] and [14].

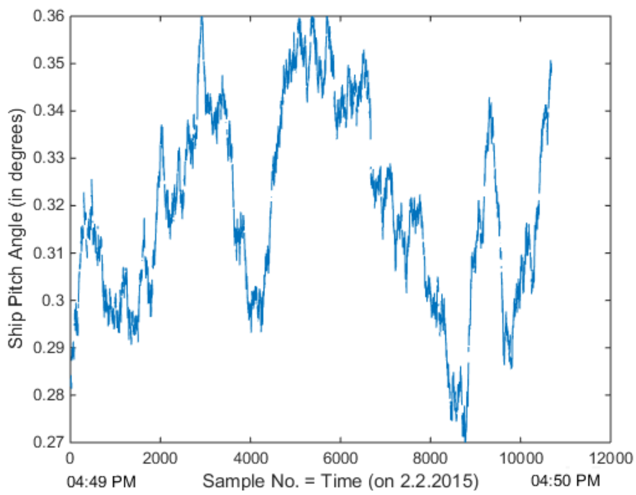


Fig. 3 Pitch of the vessel's movement due to sea waves.

This was a very simplistic computation of the relationship between sea conditions and the ship's motion. The primary challenge is not only to determine appropriate locations within the ship for installation of such sensors, but also to device algorithms for precise estimation of environmental factors based on these sensor measurements.

Therefore, significant portions of data generated by the vessel when accompanied by the date and position stamp can be invaluable for situational awareness and maritime information crowdsourcing. It will allow other ships to be aware of the weather, sea and ice conditions at a distant location, thus assisting them in making informed decisions about future route and speed plans well in advance.

Information about Coverage of Cellular Communication Service: The status of cellular coverage (3G/4G) was recorded at regular intervals during the voyage starting from Turku at 08:40 on 3rd February. A cellular service connection with an internet data package from the Finnish provider DNA Ltd was used to monitor

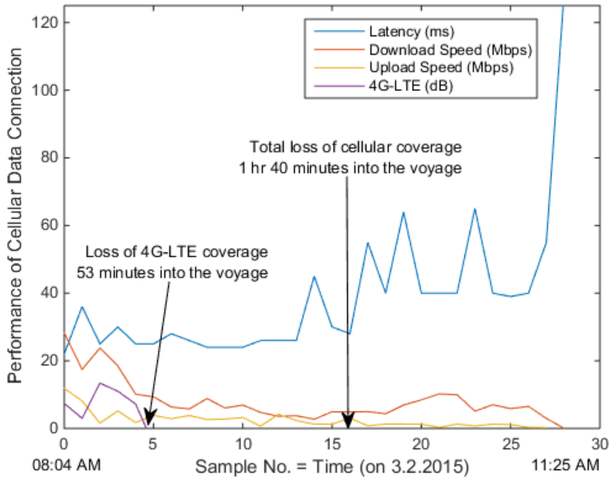


Fig. 4 Coverage of cellular communication service along a portion of the Turku-Mariehamn route.

the coverage statistics (4G-LTE signal strength, latency, and transfer speed of the cellular data connection) as shown in Fig. 4. The data was recorded until 11:25 when the vessel reached open waters outside the Turku archipelago, approximately mid-way between Turku and Mariehamn.

It can be observed in Fig. 4 that 4G-LTE coverage was lost about 53 minutes into the voyage, followed by the loss of all cellular coverage another 50 minutes later. The internet data connection statistics gradually degrade until they are unbounded after the total loss of all coverage. These results can be verified by observing the cellular provider's own coverage map [16]. Similar analysis can be performed simultaneously by other ships in the Baltic Sea. Together by pooling the contributions from each vessel, an aggregate coverage map for the entire Baltic Sea maritime region can be generated. Furthermore, the significance of such information is that the ESABALT terminal on board the vessel can be designed to select the proper communication channel cognitively by sensing the best possible medium available at that particular geo-location and time to communicate with the server for information transfer.

ESABALT FUNCTIONAL DESCRIPTION THROUGH EXAMPLE SCENARIOS

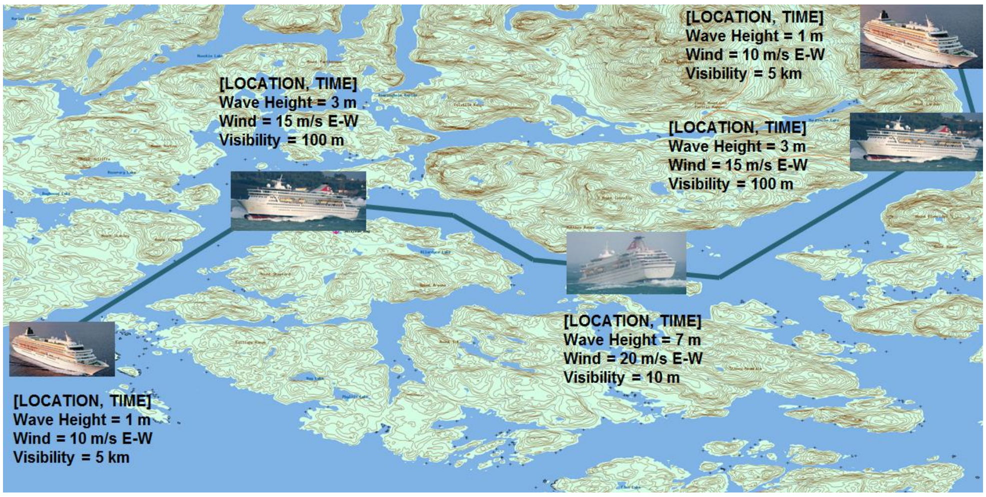
The utility of the proposed ESABALT system can be demonstrated through the following example maritime scenarios. Together, these scenarios help to support the three specialized services of intelligent marine navigation and routing information, efficient emergency response, and environmental monitoring and reporting with emphasis on use of e-Navigation techniques and cross-border cross-sector functionality.

Scenario 1 – Involving Pleasure Boats in Coastal Monitoring: During the navigable seasons pleasure boats (private sail boats, small fishing craft etc.) are ubiquitous along the Baltic coasts. The ESABALT platform operated on a tablet computer or as a smartphone application can be an effective tool to enable quick first reporting of incidents and atypical environmental observations (oil spill residue, algae bloom, shipping accidents, etc.) by operators of these pleasure boats. Authorities using ESABALT can then approach the area in question. This will enable the authorities to concentrate their efforts on small geographic areas, thus allowing efficient planning and use of resources. This benefit is especially significant when we consider the vast number of narrow archipelagos and deep coves along the Baltic coast. ESABALT ensures that the users themselves are one of the most important data providers to the system. The system will focus on raising situational awareness while the user community self-regulates the quality and correctness of the information.

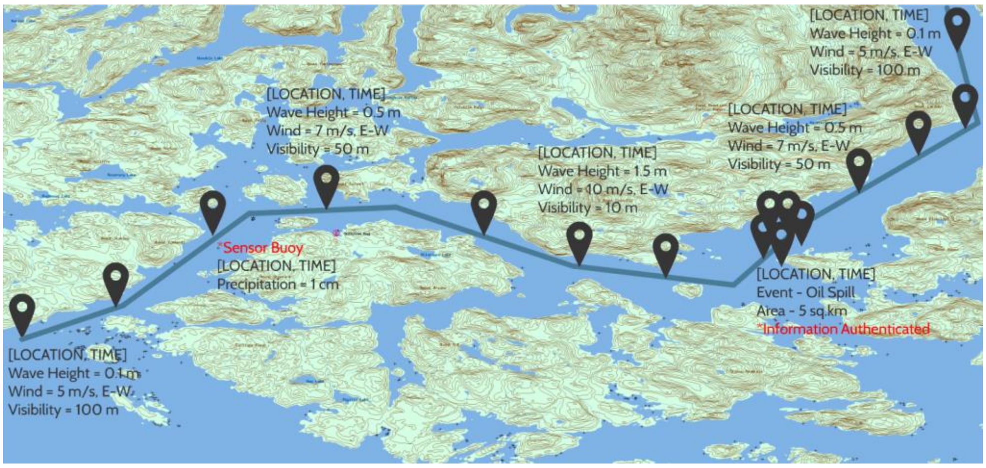
Scenario 2 – Autonomous and Incidental Data Crowdsourcing: As described earlier, cargo vessels, cruise liners and even sail boats are usually fitted with a number of sensors which provide the crew with vital and real-time information about their own ship's performance and the surrounding environment. This is illustrated by a hypothetical scenario in Fig. 5(a) and 5(b). Using state-of-art data filtering techniques some of this information along with a time and position stamp can be very beneficial for other ships planning to take the same route in the near future. This can be termed as collaborative situational awareness. Consider the scenario in Fig. 5(a), where a ship is navigating approximately 100 km through an archipelago in the North-East to South-West direction. At regular intervals the ships sensors autonomously gather information about the local prevailing sea (wave height), wind and visibility conditions and can store this to ESABALT along with the time and geolocation of the data sample. Simultaneously, other vessels and deployable sensor stations in the same area may also be contributing other vital information, such as precipitation, geolocation of a recent oil spill etc.

In the event that another ship plans to follow a similar route through the archipelago, the Navigator queries ESABALT for most current information on the situational awareness along the planned route. Fig. 5(b) shows the information which will be displayed to the Navigator. This will provide a holistic view of the expected sea, weather and environmental conditions to the Navigator, thus enabling fore-planning for the most efficient and secure route and speed along the route.

Scenario 3 – Earth Observation: There are already established channels for distribution of Earth observation (EO) images from remote sensing satellite systems. ESABALT can therefore be an alternate medium for distributing pre-processed EO images depicting clearly sea-ice characteristics, oil-spill areas and location of accidents. Moreover, harbor entry, piloting until berthing, and navigating crowded narrow waterways can be aided using real-time traffic updates via images, for example from deployable drone or balloon-based cameras, and



(a)



(b)

Fig. 5 Autonomous and incidental data crowdsourcing for collaborative situational awareness.

distributed over ESABALT. This will also contribute to safe and fuel-efficient transport in sheltered and/or inland waterways.

Scenario 4 – Common Medium of Communication between Ships and Pleasure Boats: As stated earlier, one of the primary concerns of Navigators on board cargo vessels and cruise liners in the Baltic Sea is the possibility of accidental collision with another vessel, especially one of the many pleasure boats that sail near the coast and approaches to harbors. It is not always possible to contact these boats via VHF radio (as they may carry a cellular phone instead), or sound the horn. In such situations the ESABALT platform offered on smartphone or tablet computer can be a common channel for communication between the large vessel and smaller boat. If this concept is taken further, the ESABALT system on board a vessel can act as an early detection and warning system by identifying other vessels (based on their AIS signatures) which stray too close to it - forming a sort of protective spatial zone around the vessel, and which moves with the vessel providing automatic anti-collision warning messages along the route.

ESABALT SYSTEM ARCHITECTURE

Fig. 6 describes the ESABALT system architecture as a whole. The system is designed to consist of a central data and web server which will process all the crowdsourced information from the individual ESABALT terminals, and in turn cater to their service requests. The terminals are onboard ships, which may include pleasure craft, commercial vessels and authority vessels. The onboard terminals are the primary interface to the ESABALT system and their operation is supported by the three primary technology pillars of the system – Navigation, Sensing and Communication. Also integrated into the system architecture are the land-based or sea-based sensor stations to contribute to the information provided by users about the environment around the Baltic Sea, external databases providing maps, vessel information, and earth observation images, and a central control station for administrative oversight.

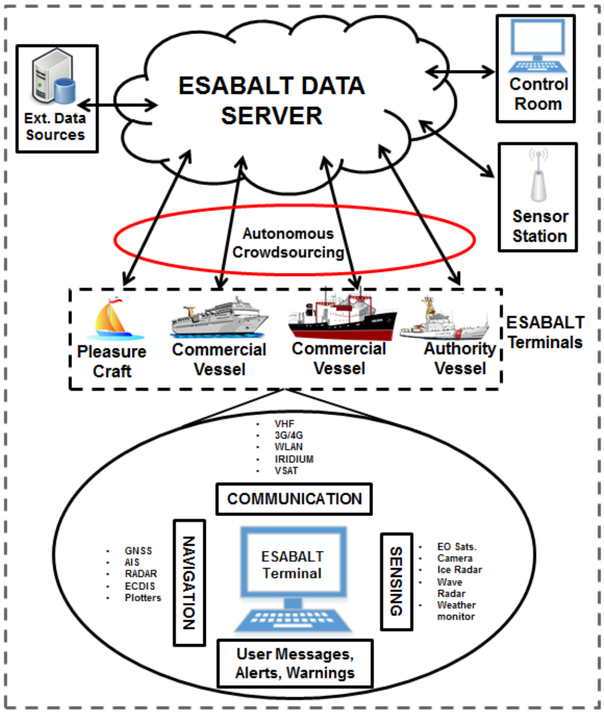


Fig. 6 ESABALT system architecture.

One of the key characteristics of the ESABALT system is *Autonomous Vessel Data-Crowdsourcing*, which includes integration of novel sensors with the ESABALT terminals onboard the vessels or in automated sensor stations so that relevant data aggregated with other sensor/AIS information is crowdsourced to the server with minimal, if not zero human intervention. This information is available to other vessels or authorities for real-time and collaborative situational awareness, as described earlier.

EXPECTED ECONOMIC AND SOCIETAL IMPACT OF ESABALT IN THE BALTIC SEA REGION

The business potential for ESABALT comprises of all those who navigate in the Baltic, in a commercial as well as non-commercial capacity. ESABALT is planned to be free for end-users, but paid by other subscribers, such as harbors, shipping companies, and small-to-medium enterprises (SMEs) implementing innovative services and applications on top of the crowdsourced and location-based maritime data. It will provide benefits from an open-source type of a maritime platform, simultaneously demonstrating that a trusted, independent intermediary can collect, process, and store location and other maritime data using transparent and clearly documented methods. ESABALT will also contribute towards fuel-efficient and safe shipping resulting in reduced insurance costs. Integrating pleasure boats into the data crowdsourcing will enable them to contribute to coastal surveillance and monitoring, thus reducing the burden on already resource-strapped coastal authorities. ESABALT can be allowed to serve as a service design proof-of-concept and an information infrastructure for regional economic growth. Therefore, the system impact can be summarized in three categories; increased information sharing, increased number of users and aggregated information overview across national boundaries and administrative sectors.

ESABALT is strongly aligned with the objectives of the BONUS program especially, *Developing improved and innovative observation and data management systems, tools and methodologies for marine information needs in the Baltic Sea region*. ESABALT also contributes towards the *Save the Sea* objective of the European Union Strategy for the Baltic Sea Region. It directly addresses the Strategy's Policy Area Maritime Safety and Security (PA SAFE) in the part that focuses on the ‘Reduction in the number of maritime accidents’. By delivery of current, high-quality, integrated navigation-support data the project offers specific tools for situational awareness and accident prevention thus contributing to the PA Actions *Develop co-operation in maritime surveillance and information exchange* and *Improve safety of navigation by means of e-Navigation and new technology.*

CONCLUSION

In this paper we have described some of the operational scenarios and the architecture of the proposed ESABALT system - a potential solution for enhancing situational awareness in the Baltic Sea maritime domain. ESABALT is a feasibility study towards implementing an open mechanism for the crowdsourcing of maritime information for the benefit of all maritime stakeholders in the Baltic Sea Region. Ships, maritime personnel (seafarers, coast guard, search & rescue, VTS, etc.) and sensor stations will be the primary sources and beneficiaries of the information. Only such information will be crowdsourced which is critical for enhancing maritime safety and security, environmental monitoring, and emergency response in the Baltic Sea Region. The test and data collection campaign on board ‘Amorella’ was an exercise in identifying such information. The paper also describes the expected societal and economic impact of the proposed system. In addition, though the ESABALT concept is targeted to the Baltic Sea, the system has potential to be adaptable also for the Arctic regions.

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