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Original article

Autonomous Unmanned Merchant Vessel and its Contribution towards the e-Navigation Implementation: The MUNIN Perspective*

Hans-Christoph BURMEISTER [1], Wilko BRUHN [1],
Ørnulf Jan RØDSETH [2], Thomas PORATHE [3]

[1] Fraunhofer Center for Maritime Logistics and Services CML, Hamburg, Germany, Hans-Christoph.Burmeister@cml.fraunhofer.de
[2] MARINTEK Department Maritime Transport Systems, Trondheim, Norway
[3] Chalmers Department of Shipping and Marine Technology, Gothenburg, Sweden

Abstract

While IMO's e-Navigation project's scope is to enhance safety of navigation by improved ship-to-shore-cooperation, the EU's FP7 project MUNIN's aim is to develop a concept for an autonomous dry bulk carrier, that is at least as safe as a manned vessel. As e-Navigation has a strong focus on improving the human element in shipping and MUNIN tends towards an unmanned bridge, a common baseline might look quite contradictory at first, but they share the need to ensure and enhance the safety of navigation. After an introduction into e-Navigation and the MUNIN project, this paper will demonstrate with two examples, how MUNIN's results address identified e-Navigation's gaps and addresses e-Navigation's user needs. Thus, MUNIN contributes to the development and implementation of the prioritized e-Navigation solutions.

Keywords: unmanned vessels, autonomous navigation, e-Navigation, maritime safety

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I. Introduction

Driverless transport systems are already state-of-the-art on certain transport legs and also in the maritime domain, autonomously operating subsea vehicles for research purposes have already been in practice for several years. Applying this idea on merchant vessels provides a potential holistic solution to cope with the ever increasing sustainability demands on maritime transportation (Rødseth and Burmeister, 2012). Within the European Union, the MUNIN project (Maritime Unmanned Navigation through Intelligence in Networks) develops a concept for an unmanned dry bulk carrier during deep-sea voyages. The vessel itself will be in an autonomous mode allowing it to act independently within a certain degree of freedom, but being monitored constantly from a shore based control station (Rødseth et al, 2013). The project includes a validation of the intended concept and an assessment of the technical and legal feasibility as well as a cost-benefit analysis. With regards to navigation, MUNIN especially focuses on the development of advanced and integrated sensor systems for automated lookout, autonomous navigation systems incorporating COLREGs and safe operation in harsh weather, a safe and reliable ship-to-shore communication architecture as well as human-centred design of onshore monitoring stations (Burmeister et al, 2014).

In parallel to these activities, there is the e-Navigation initiative going on, which was launched by the IMO in 2005. Even though the development of a completely unmanned vessel is beyond the current scope of e-Navigation, there are several similarities between both efforts so that MUNIN can presumably contribute to certain areas of the prioritized e-Navigation-solutions (Burmeister and Rødseth, 2014). The baseline of the paper is a short introduction into e-Navigation, its identified user needs, gaps and solutions as well as an overview of the MUNIN project, its architecture and operational modes. Then, this paper outlines in detail how solutions developed within MUNIN also address identified user need and how the projects intends to support the development of the prioritized e-Navigation solutions.

II. e-Navigation

E-Navigation is an IMO initiative started in 2005 to increase the safety of navigation by modern technology. The scope of the e-Navigation project is defined as "*the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment*" (IMO MSC 2009). E-Navigation foresees progress in the three fields of:

- On-board navigation systems,
- Shore side vessel traffic information management and
- Ship-to-ship-, ship-to-shore and shore-to-shore-communication infrastructure.

Thereby, it was noted that on-board navigation systems could, for example, benefit from a better integration of own ship sensors and standard user interfaces, while the shore management could profit from more comprehensive, but easily understandable data provided by a seamless information transfer. Since then, several research projects have started to investigate special issues with regards to the prioritized issues, such as e.g. ACCSEAS, MONALISA, AVANTI or EfficienSea. However, to understand MUNIN's possible contributions, the process of e-Navigation must be recapitulated on a high-level:

2.1. Identified user needs

At the beginning of the e-Navigation process, the user needs were gathered in a world-wide survey. In 2009, they were presented in a report to the 55th NAV session (IMO NAV 2009). While the whole survey investigated more than ten issues in detail, only a few of these results with relevance to the MUNIN project are mentioned below.

Regarding communication and shore support, the report outlined amongst others, that officers feel distracted from their navigational duties by excessive reporting requirements, which should be harmonized and where double reporting should be avoided so that more time could be used for the navigational tasks to increase safety. In addition, the officers would be in favour of using a broadband satellite communication for ship-to-shore communication to keep the VHF channels free for important safety communication. Furthermore, most respondents were also in favour of a more strategic coordination of the maritime traffic by shore-side stakeholders.

In respect to the officer's direct work environment and the navigational displays, the report outlined amongst others the need for less, but more relevant and necessary information which should be presented in a simpler and more intuitive way. This would help to avoid information overload onto the officers, but nevertheless ensure high situation awareness under all circumstances. In addition, a new central alarm management system including prioritization issues has been mentioned as a desired tool from the participants.

2.2. Results of the gap analysis

Continuing this work, a detailed gap analysis was conducted within the e-Navigation initiative to identify the current status, determine the gap to the aspired situation and derive means to achieve this status. The results were finalized and presented at the 58th NAV session in 2012 (IMO NAV 2012). It contains a list that distinguishes user gaps into different operational areas and proposes e-Navigation solutions to be addressed in the operational, technical, regulatory and training domain. Amongst others, this contains the following identified gaps:

- Communication and information
  - o Lack of assessment procedure to quantify reliability parameters (e.g., specific assessment of electronic position fixing systems);
  - o Lack of automatic assessment functionalities to provide quantified reliability information;
  - o Insufficient reliability of data/voice communications;

o Insufficient use of IMO Standard Marine Communication Phrases (SMCP);
o Lack of good human machine interface for the communication means;
o Bandwidth limitations shore to ship;

- Ship operation
  o Lack of effective and harmonized means for assessment of the accuracy and plausibility of indicated information;
  o Lack of assessment procedure to quantify reliability parameters (e.g., specific assessment of electronic position fixing systems);
  o Lack in presentation of manoeuvring information/data (engine-room telegraphs) on navigational display;
  o Lack of standardization for operation of functions to observe the passage plan. Users require standardization on the level of function provided and the operating way of it;
  o Inaccurate AIS data;

- Shore services
  o Lack of harmonized presentation of domain awareness to improve situational awareness for allied and other support services;
  o Traffic monitoring tools that have the capability to manage increased levels/volumes of information are not in use;
  o Lack of procedures that enable shore based authorities to monitor quality of navigation systems on board as well as quality of information and effectiveness of communication;

2.3. Prioritized e-Navigation-solutions

Due to the high number of proposed solutions, they were further analysed with regards to risks and cost-benefit ratio to prioritize the starting solutions. Thereby, the aim was not to restrict the scope of e-Navigation, but to start with the most promising solutions during the first implementation phase. Based on this result, the 59th NAV session then decided to prioritize the following five main solutions (IMO NAV 2013):

- S1: improved, harmonized and user-friendly bridge design,
- S2: means for standardized and automated reporting,
- S3: improved reliability, resilience and integrity of bridge equipment and navigation information,
- S4: integration and presentation of available information in graphical displays received via communication equipment an
- S9: improved Communication of VTS Service Portfolio.

As it can be seen, most solutions refer to the issue of improving communications between all stakeholders, including shore based users, as this is one of the major gaps identified.

III. Economic model

Aiming to develop a concept for unmanned and autonomous ship operation, MUNIN is a research project funded by the European Commission's Seventh Framework Programme to conduct a technical, legal and economic feasibility study for an unmanned vessel. Its base hypothesis is that *"unmanned ship systems can autonomously sail on an intercontinental voyage at least as safe and efficient as manned ships*". This shall be tested within the project with the help of an integrated simulation environment to allow for a concept test in real-time.

While the name is an acronym for *Maritime Unmanned Navigation through Intelligence in Networks,* it also makes reference to a character from Old Norse mythology. Munin, meaning memory or mind, is one of the god Odin's ravens who flies around the world independently during the day and distributes what he has gathered to his master in the evening. Like the raven, the unmanned ship shall travel autonomously around the world, but will return safely home to its harbour.

3.1.MUNIN's vision and rationale

The basic motivation to develop an unmanned and autonomous ship is to contribute to the aim of a more sustainable maritime transport industry. As a large proportion of worldwide forwarding is carried out by sea it may be considered to be one of the main driving forces of today's global economy.

At present, a fierce competition between shipping companies is putting a lot of economic pressure on all parties involved in maritime transportation. At the same time, international legislation increasingly imposes requirements to reduce ship's ecological impact. This imperative to reduce costs and emissions has lead shipping companies to the conclusion that slow steaming can be part of the solution to their current challenges. This though, has the unfavourable ancillary effect of increasing voyage times, thus creating an even higher demand for seagoing personnel. Although the lack of qualified masters, officers, engineers and even ratings, especially in Europe, has been obscured to a certain degree by the current shipping crisis, most parties agree that there will be a factual shortage in the long run (BIMCO 2010).

The development towards an unmanned and autonomous ship represents a comprehensive solution to meet those three major challenges of the maritime transport industry:

- Keep operational expenses as low as possible to facilitate efficient international trade,
- Reduce environmental impact and emission of greenhouse gases and
- Remove trivial operational tasks and release crew for more demanding and interesting work, to attract and retain seagoing professionals.

While slow steaming will reduce fuel costs and greenhouse gas emissions, it will entail higher costs due to longer sailing times which in turn have an impact on crew cost, ship hire and the probability of technical faults and related off-hire penalties. Except for charter hire, autonomous ships will address the other two issues: crew costs are eliminated and necessary reliability enhancements will mostly avoid off-hire. Thirdly, it will also open new professional perspectives for mariners. Instead of being disconnected from home for many months, the concept envisages highly qualified shore-based positions (Rødseth et al. 2012).

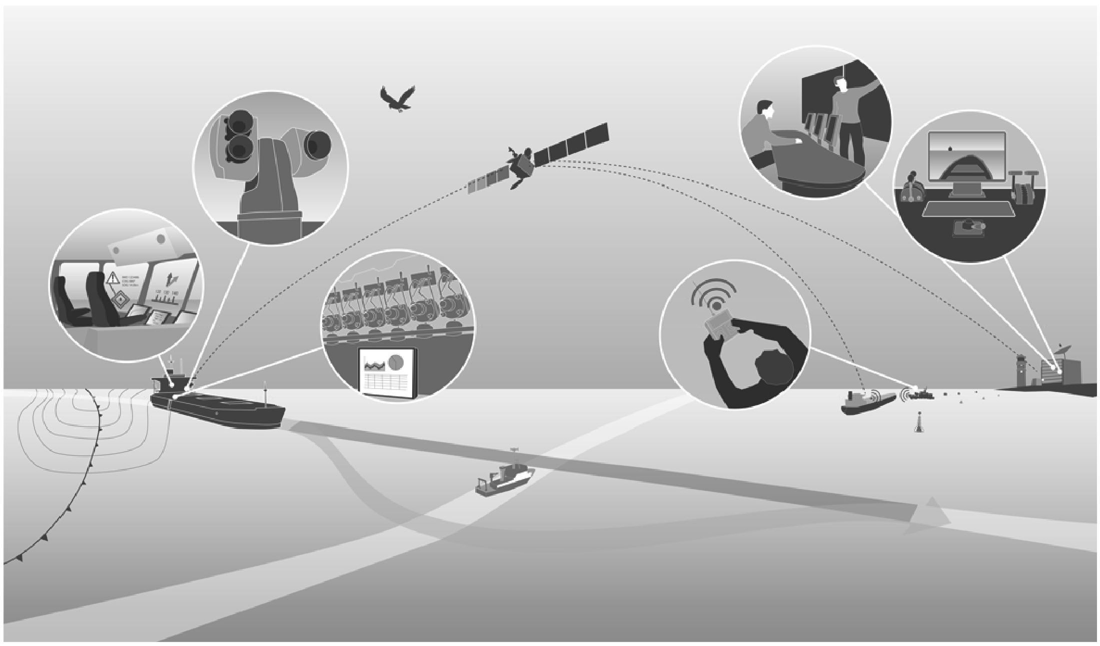

Figure 1: MUNIN's vision

Hereby, the autonomous vessel is described as a ship equipped *"with modular control systems and communication technology to enable wireless monitoring and control, including advanced decision support systems and the capabilities for remote and autonomous operation"* (Waterborne TP 2011). The use case investigated in MUNIN is a dry bulk carrier operated in intercontinental trade. This type of trade bears a high attractiveness for the MUNIN concept, as additional cargo management requirements are low, the attractiveness for slow steaming is high and dry bulk carriers normally transport cargo from point to point, resulting in a long uninterrupted deep-sea voyage as compared to other vessels e.g. container vessels. This is an important characteristic, as the vessel will not be operated unmanned from berth to berth, but rather from (deep-sea) pilot point to (deep-sea) pilot point. During approach, berthing and de-berthing, a crew will still be on-board and will classically operate the vessel, even though the advanced technology of MUNIN might assist them. At the (deep-sea) pilot point, this onboard control team will be picked up together with the pilot and the control will be handed over to the on-board autonomous navigation system that operates the vessels autonomously following a predefined voyage plan. Nevertheless, a new entity, the shore based control centre, will constantly monitor and control the autonomous operation, and might even take over direct remote control in exceptional circumstances.

3.2. MUNIN architecture

Even though vessels are already highly automated today, some new systems and further integration efforts are necessary to enable unmanned and autonomous operation in the MUNIN context to, for example, compensate for the cognitive tasks of the officer-of-the-watch on board and to bridge the gap between the vessel and the physically disconnected monitoring humans (Porathe et al. 2014, Walther et al. 2014). However, restricted satellite bandwidth in certain regions and high communication costs make a direct and bandwidth-intensive remote control solution unattractive. Thus, MUNIN proposes a concept, where the ship is autonomously operated within certain limits by new systems on board the vessel. The monitoring and control functions outside defined limits are executed by an operator ashore in the Shore Control Centre. Based on a detailed task analysis of today's processes in Bruhn et al 2013, the MUNIN concept defines the following systems and entities (see also bubbles in figure 1) :

- An Advanced Sensor Module, which takes care of the lookout duties on board the vessels by continuously fusing sensor data from existing navigational systems, e.g. radar and AIS, combined with modern daylight and infrared cameras;
- An Autonomous Navigation System, which follows a predefined voyage plan, but with a certain degree of freedom to adjust the route in accordance with legislation and good seamanship autonomously, for example, due to an arising collision situation or significant weather changes;
- An Autonomous Engine and Monitoring Control system, which enriches ship engine automation systems with certain failure prediction functionalities while keeping the optimal efficiency and which also takes care of the additionally installed pump-jet that acts as rudder and propulsion redundancy;
- A Shore Control Centre, which continuously monitors and controls the autonomously operated vessel by its skilled nautical officers and engineers;

Hereby, the latter represents the human element within the technical control loop. It comprises amongst others the certain positions (Porathe and Costa, 2014):

- A Shore Control Centre Operator, who monitors the ship operation of several autonomous ships at the same time from a desktop cubicle station and controls the vessels by giving high level command like updating the voyage plan or the operation envelope of the autonomous system;
- A Shore Control Centre Engineer, who assists the operator in case of technical questions and who is in charge of the maintenance plan for the vessels based on a condition-based maintenance system ensuring sufficient reliability of the technical system for the next autonomous journey;
- A Shore Control Centre Situation Room Team that can take over direct remote control of one vessel in certain situations via a shore side replica of the unmanned vessel's bridge

including a Remote Manoeuvring Support System that ensures an appropriate situation awareness in direct control despite the physical distance of crew and vessel;

For the on board systems, a redundant architecture has been chosen (Rødseth et al., 2013). This architecture approach ensures that the vessel is on the one hand always monitored and controlled by a human ashore, e.g. by the definition of operational limits of the autonomous system. On the other hand, the combination of these operational limits and the autonomous systems also minimize the operator's load to allow for the monitoring of multiple ships by one operator while reducing communication requirements and costs, as restricted remote control is still possible, even if only a low-capacity L-band channel is available (Rødseth et al., 2013). Furthermore, MUNIN's approach of installing autonomous acting system on the vessels also facilitates implementing fail-to-safe-functionalities on board, which ensures safety of navigation and operation during possible communication disconnections (Rødseth and Tjora, 2014).

3.3. MUNIN operational modes

When in operation, the mode of the unmanned vessel can be distinguished into five different states (see also figure 2) (Rødseth et al., 2013) :

- Manned operation,
- Autonomous execution,
- Autonomous problem-solving,
- Remote operation and
- Fail-to-safe.

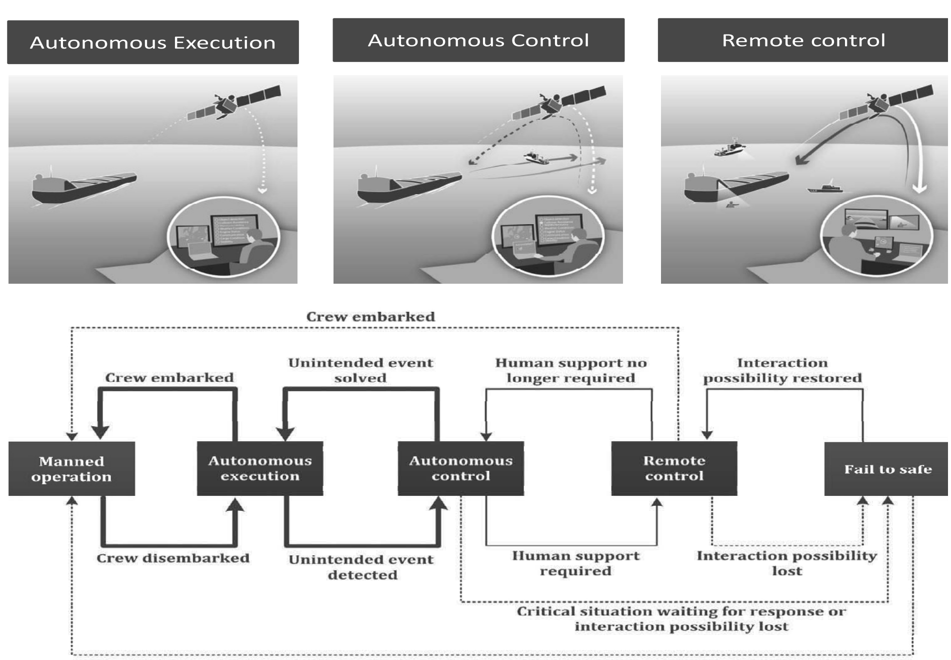

Figure 2: MUNIN's operational modes

Hereby, manned operation represents the mode, where the vessel is handled by a normal crew on-board, as this is e.g. the case during berthing and approach. When the crew leaves the vessel, the ship's status switches to autonomous execution, where the autonomous systems on-board constantly measure the ship conditions and observe the environment to determine if the vessel can still follow the predefined voyage-plan. Additionally, it provides the shore control centre with regular data updates to allow them to conduct their monitoring tasks with the necessary situation awareness. In case of the need for deviations inside the ship's defined operational freedom, the vessel changes to autonomous control, where it can change the voyage plan on its own to ensure safety, for example due to a crossing vessel or changing weather condition. Based on the given constraints by the shore control centre, an enhanced feedback loop might be required.

Regardless of the current status, the shore control centre can of course intervene at each stage and might even take over direct remote control for general or specific situation handling (Porathe et al. 2014). In such cases, the autonomous capabilities are switched off and all data is relayed to a shore side bridge, where a skilled nautical crew takes over the ship handling and feed the respective commands back to the vessel. This represents a pure remote control approach, which is only activated during certain special situations or to train the officers with that procedure. In addition, a fail-to-safe mode is foreseen, which only aims at ensuring safety of the ship by certain procedures, which may imply that the voyage to its destination is temporarily suspended.

IV. MUNIN's contribution to e-Navigation

In most studies, human errors are part of the root cause of most maritime accidents (Blanding 1987, Sandquist 1992, Rothblum 2000). Today, human operators on the bridge are exposed to fatigue, stress and adverse condition, as the bridge manning is down to a minimum. Moving the operator to the relatively protected workplace of a control room on land, some of the risks of human error can be mitigated. However, it must be respected that new types of hazards may appear in the new relationship between the unmanned vessel and the remotely located human operators which may not be fully aware of the actual conditions on the scene. This safety equation will attract much focus on the human factors research in this project, and certainly leave room for many further studies. Despite this on-going research, it can already be concluded that the development towards an autonomous vessel does at least provide a potential to increase navigational safety (Burmeister et al. 2014). Thus, MUNIN can also contribute to e-Navigation's aim of increasing navigational safety, even though MUNIN's origin is a novel approach to sustainability in shipping. In the following, these contributions shall be elaborated for certain examples.

4.1. Improved reliability of navigation information by the advanced sensor module

One of the identified gaps within e-Navigation is the lack of means to assess the accuracy and plausibility of indicated information. Of course, further overloading the officer-of-the-watch with additional reliability indicators should be avoided, as this would be counterproductive with regards to the user needs. However, e-Navigation suggests a solution that automatically assesses the accuracy, plausibility and reliability of the information and only provides the required information to the user.

An area, where MUNIN's development can contribute to, is its developed concept of the advanced sensor module, which conducts the lookout duties on-board the unmanned vessel. This system basically fuses the information provided by different sensors, like radar, AIS, visual video and infrared cameras and creates a perceived world-model out of it containing the different detected objects, their tracks and navigational statuses, but also an indication about the reliability of the object detection (Burmeister et al., 2014). Using enhanced radar detection algorithms, additional data can be generated that allows further crosschecking with the additional sensor data. This allows e.g. detecting small objects not emitting AIS information, but also false or inaccurate AIS-targets by sensor and feature processing. On board the MUNIN vessel, the autonomous navigation system is thus provided only with data pre-processed by the advanced sensor module, which now only contains one target per vessel including a reliability indication, based on the degree of successful cross-checks between the radar-extracted features and additional sensor data. This module and its detection capabilities have already been successfully tested in Norwegian waters during a voyage of a vessel from the coastal administration (Bruhn et al., 2014).

Decoupling the autonomous navigation system, the advanced sensor module can of course also be applied on a manned vessel as an e-Navigation solution. On the bridge, it could assist the officer-of-the-watch in filtering and assessing data about other vessels and objects in its vicinity, as a mean to reduce information overload and even conflicting information from different detection sensors, like radar and AIS, and instead providing the mariner with what is needed: a list of ships and other objects with their positions, their types and movements so that the proper action in accordance with COLREG can be taken.

4.2. Shore-side monitoring by integrating and presenting available information in graphical displays

Limited bandwidth in ship-to-shore communication is regarded as one e-Navigation gap and especially on the high seas this is doubtlessly true. Increasing ship-to-shore bandwidth, e.g. by WiMax or 3-5G cellular technology, might certainly be a solution for coastal waters. However, regarding the coexisting perceived information overload, it can be argued that providing the right information instead of more data is an even better solution.

MUNIN intensively deals with the fact, that monitoring personnel ashore has sufficient situation awareness in areas of restricted bandwidth, while keeping the satellite communication costs at a low and acceptable level. Therefore, the information needs have been identified and grouped into nine functions that will be displayed on a dashboard (Porathe et al. 2014). For these groups, the development of functional status indicators is envisaged. These allow monitoring of the health status of ships on a high-level based on this bandwidth optimized indicator data. These indicators can be compressed to a very small message and will be sent regularly to shore. In case of status changes, additional information is automatically attached to the message to allow the personnel to assess possible consequences of the detected anomaly. Thereby, the prior connection between technical systems and navigational functionalities allows a rapid assessment of the functional consequences of technical failures ashore with a minimum use of bandwidth and operator attention (Rødseth et al. 2014).

Within e-Navigation, the MUNIN results on how situational awareness of shore side personnel can be ensured in spite of reduced bandwidth can also be used to optimize shore-side monitoring. This comprises the knowledge with regards to necessary detailed information needs as well as the high-level monitoring approach via functional status indicators. As a first step, these improved monitoring functionalities could, for example, be used to augment the navigational assistance services – a shore based service, which assists on-board navigational decision-making – provided by vessel traffic service centres (IMO 1997). Thereby, MUNIN's functional-oriented approach also addresses the user need for a new central alarm management system including prioritization issues.

V. Outlook and conclusions

E-Navigation is focusing on increasing the safety of navigation by a better integration of ship and shore. With regards to that scope, it was demonstrated how the results and research progress achieved within the MUNIN project on autonomous vessels can contribute to the development and implementation of e-Navigation solutions, irrespective of the ship being manned or not. Besides the given examples, there are of course further areas where MUNIN results have a potential to improve navigational safety, like e.g. operations of vessels in harsh weather (Walther et al., 2014) or automated COLREG-compliant navigation (Burmeister and Bruhn, 2014).

As MUNIN's feasibility study is not yet completed and the detailed concept tests and the technology assessment are currently on-going by means of ship handling simulation and in-situ testing, the proposed concepts represent a preliminary stage. Thus, before deriving separate e-Navigation solutions from the proposed concepts, the final feasibility results must be awaited before all practical implications of the MUNIN project can be assessed.

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