Final Report Summary - MUNIN (Maritime Unmanned Navigation through Intelligence in Networks)

Executive Summary:
The MUNIN project developed a technical concept for the operation of an unmanned merchant vessel and assesses its technical, economic and legal feasibility. 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 requirements are low, slow steaming is highly attractive and dry bulk carriers normally transport cargo from point to point resulting in a long, uninterrupted deep-sea voyage. This is an important characteristic, as MUNIN only envisages autonomous operation of an unmanned vessel during deep-sea-voyage, but not in congested waters or during the approach. Those tasks will still be executed
by a crew on board, though the deep-sea/voyage-length ratio is an important economic factor for the operational efficiency.

MUNIN propose a concept, where the ship is autonomously operated by new systems on board the vessel, but the monitoring and controlling functionalities are executed by an operator ashore. Thus, the MUNIN concept defines the following systems and entities and implemented them as prototypes:

- An Advanced Sensor Module, which takes care of the lookout duties on board the vessels by continuously fusing sensor data from existing navigational systems 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 autonomously, e.g. 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-pre-detection functionalities while keeping the optimal efficiency;
- A Shore Control Centre, which continuously monitors and controls the autonomously operated vessel after its being released from its crew by its skilled nautical officers and engineers.

A financial analysis of the developed concept for a new build MUNIN showed that compared to a conventional manned bulker the autonomous bulker would be commercially viable under certain circumstances. In a base scenario the MUNIN bulker is found to improve the expected present value by mUSD 7 over a 25-year period. Besides personnel cost savings the fact that the autonomous ship makes changes in ship design possible ensures a positive expected present value. Such new innovative autonomous ship designs should make a reduction of fuel consumption (and emissions) possible. However, this is assuming that the depicted challenge of autonomous heavy fuel oil operation could be solved. But even if that event does not occur, unmanned vessels also bear efficiency potentials for certain niches, like e.g. short sea shipping in emission control areas.

Regarding safety, 50% of all total losses are related to collision and foundering. Furthermore, in most maritime accidents human errors are a crucial part of the root cause of most maritime accidents. A decrease of collision and foundering risk by around ten times compared to manned shipping was found to be possible, mainly due to the elimination of fatigue issues. Nevertheless, risks from cyber-attacks, engine breakdown and fire are issues that cause concern. However, it should be possible to design ships and redundant systems that have a very high resilience against such events.

For the legal framework, the principal areas of concern are navigation and manning: in both cases, the unmanned ship will significantly alter the practical state of play, with likely legal consequences. However, overall it can be concluded that the unmanned ship does not pose an unsurmountable substantial obstacle in legal terms. In terms of liability, the biggest issue will concern the attribution of the existing ship master duties to the relevant and adequate persons involved in the operation of an unmanned ship.

Especially in Europe, shipping companies have to deal with a demographic change within a highly competitive industry, while at the same time the rising ecological awareness exerts additional pressure on them. The autonomous ship represents a long-term, but comprehensive solution to make maritime transport more sustainable. Shore-based seafaring also opens new professional perspectives for mariners that can now remain connected to their social life. This can help to attract new, highly qualified...
professionals.

Project Context and Objectives:
The idea of autonomy or "intelligent" unmanned operation have been around since the advent of computers and arguably also before that. The first attempts were on land and later under water. More recently, the air and the sea surface have also become experimental grounds for such vehicles. Some systems have been turned into commercial success, in particular in sub-sea exploration and in land transport. Storage houses, ports and mines are using automated guided vehicles (AGV) and subsea surveillance vehicles are available from commercial suppliers. In the naval field, autonomy is starting to be commonplace. Relatively large craft, up to 16 m, has been demonstrated. However, large unmanned merchant ships have until recently not really been considered as a serious possibility. They seemed to be too large and consequences of any mishap too severe to be contemplated. The WATERBORNETP strategic research agenda from 2007 listed the autonomous ship as one of the exploitation outcomes (EO3), but this was more about automation and sensors than an actual unmanned ship. However, this was the starting point for MUNIN.

The premise at the outset of MUNIN was that unmanned ship is a very interesting prospect in the maritime business, particularly in light of the tendency to reduce speed to save fuel and the impact this would have both on crew costs and crew welfare due to much longer voyages. When MUNIN started, this was a fairly exotic idea and it was expected that quite a bit of negative public comments would arise. This turned out to indeed be the case, but at a much lower level than expected. As the project moved on and more results emerged, it is safe to say that many of the negative voices silenced and was replaced by positive responses. The recent launch of several other projects on unmanned ships is proof to this. It is more than probable that the activities in and the publications from MUNIN has triggered a much wider and global interest in unmanned shipping.

Unmanned ships are not trivial to develop or deploy as they seem to be contrary to many of the international conventions and regulations that govern international shipping. There are also obvious technical problems that have to be solved before this can be a reality. The organisation of MUNIN is directly reflecting these problem areas:

- **Architecture (WP4):** Ship-shore communication technology and safety, security and reliability of integrated ship data networks. Ships without crews will in most cases be much more dependent on availability of shore resources and this requires high availability ICT systems.
- **Autonomous Bridge (WP5):** Bridge functions to plan, sense and manoeuvre a ship without a crew on board. For safety, this is perhaps the most obvious function. The ship must be able to sense surroundings and manoeuver to avoid accidents by sensor and computer support alone.
- **Autonomous Engine Room (WP6):** Systems and procedures to run the ship's technical systems for weeks at a time without human intervention. This is perhaps less obvious, but the crew on manned ships use much of their time doing maintenance on the ship and ship systems that will not be performed on an unmanned ship. Also, many technical systems on the ship are dependent on frequent human intervention to operate reliably.
- **Shore Control Centre (WP7):** Establishment of shore support functions, including a continuously manned short control centre. It will be necessary with new types of shore monitoring and control facilities to operate unmanned ships.
In addition to these technical and operational issues, the legal and contractual problems were also dealt with within each of the technical work packages.

From the outset, the concept ship in MUNIN was defined as a retrofitted handymax dry bulker of about 50,000 to 75,000 dead weight tonnes. The main problems were identified as described above and the mentioned technical work packages worked with the solutions and prepared prototypes for validation in WP8 Proof of concept. As the project was a concept study and to avoid excessive costs related to hiring ships for trials, the validation was planned to be done mainly with the use of simulators, using real world data were relevant. The latter was particularly relevant for sensor data and object classification. Although it was fairly certain that the technical and operational problems could be solved, the cost-benefit of the finished concept ship was not so clear. To verify also the commercial viability of the concept, WP9 Assessment would prepare a cost-benefit analysis and WP10 Future Concepts would propose alternative or additional concepts to the dry bulker. WP1 to 3 handled administrative issues, technical coordination, dissemination and IPR issues.

Specifically and from the outset, the objectives of MUNIN were to:

- Develop the technology concept needed to implement the autonomous and unmanned ship. The developed technology concept will also include shore based systems, such as VTS, Search and Rescue (SAR) and a new remote operation centre.
- Develop the critical integration mechanisms, including the ICT architecture and the cooperative procedural specifications, which ensure that the technology works seamlessly together enabling safe and efficient implementation of autonomy.
- Verify and validate the concept through trials including a wide range of scenarios and critical situations where hardware-in-the-loop data is integrated in industrial simulator systems.
- Document and provide a roadmap for how this technology and ship autonomy can be applied in other trades, e.g. European short sea shipping.
- Document and show how this technology, together with new and more centralized operational principles gives direct benefits for non-autonomous ships, e.g. in reduced off-hire due to fewer unexpected technical problems and reduced hull injury due to better systems for detection of floating objects.
- Document how legislation and commercial contracts need to be changed to allow for autonomous and unmanned ship. This applies to the general laws of the sea (UNCLOS etc.), safety at sea (SOLAS and related instruments) and commercial relationships, including insurance.
- Provide an in-depth economic, safety and legal assessment showing how the MUNIN results will impact European shipping competitiveness and safety in the above target areas: Bulk trade; Short sea shipping and in near future non-autonomous shipping.

All objectives have been met and the results are described in the following sections. A general principle in all these results is the KISS principle: Keep it Simple and Stupid. An unmanned ship is a challenging concept and it is necessary to keep the complexity of technical solutions as low as possible, both to get the necessary reliability level, but also to minimize the need for human maintenance and interventions.

One of the consequences of this was that the "shore control centre" (SCC) was included in the concept already before the project started. Having a continuously manned SCC monitoring the ship and being able to take over remote control in difficult situations was believed to be a prerequisite for developing a cost-effective concept. Without an SCC, the ship would require extremely complex software to handle all
eventualities. With an SCC, the ship will still be able to handle the majority of all situations autonomously, but can fall back on shore control for the remaining extremely difficult to handle automatically in rare cases. Also, the SCC ensures that the ship can operate safely with limited flexibility and that it does not deviate too much from plans during its mission.

The KISS principle and other design principles and methods used in MUNIN will also have general applicability to a special class of autonomous systems. This class is called industrial autonomous systems and these are characterised by being designed for cost-effective operation in a directly commercial value creation process. In contrast to some military, scientific and academic systems, the industrial autonomous system has to be proven to have a quantitative positive commercial benefit compared to expected costs. This puts much more emphasis on simplicity, humans in the loop to minimize the level of autonomy and always a need to design deterministic systems that are doing exactly what they were told to do.

Project Results:
In principle, the feasibility study on unmanned vessels conducted within MUNIN took place in different steps. First, the technical concept was developed and prototypes implemented within the four technical work packages:
- WP4 Architecture,
- WP5 Autonomous Bridge,
- WP6 Autonomous Engine Room and
- WP7 Shore Control Center.

The evaluation and assessment of unmanned vessel’s concepts was then conducted with the three work packages:
• WP8 Proof of concept,
• WP9 Assessment and
• WP10 Future concepts.

Hereby, WP8 focussed on the technical feasibility providing feedback directly to the prototype development of the technical work packages, while WP9 and WP10 assessed and evaluated the impact of the technical solutions proposed. In doing so, MUNIN partners contributed to twelve different scientific/technical areas. Table 1 gives an initial overview about these areas and which deliverable of the respective work package contains input to them. Details regarding these results are indicated later in the report after a short summary of the respective work packages.

WP4 WP5 WP6 WP7 WP8 WP9 WP10
1 Anti-collision D5.3
(D5.4) D8.6
2 Autonomous navigation (D4.8) D5.4
D5.5 D8.6
3 Efficient operation D6.8 D8.7 D9.3 (D10.1)
4 Improved system robustness D4.8 D6.5
D6.6 (D7.4) D9.2
D9.3 D10.1
D10.2
5 Improved planned maintenance D6.7 D8.7
6 Improved interaction between ship and coastal parties D7.6 D8.8 D10.3
Table 1: Overview of S&T-areas and its relation to the work packages

WP4: ICT Architecture
The objective of WP4 was to provide high quality and high integrity communication and information interfaces for the MUNIN project simulations as well as work with international standards organizations to establish the necessary ICT framework for future unmanned (and other advanced ships).

Related to progress beyond state of the art, the WP was mainly contributing to “B1.2.4. Improved system robustness” and “B1.2.11. Improved ICT architecture”. This includes contributions to the emerging e-Navigation and e-Maritime frameworks in IMO and EU. In addition to this, the WP has also contributed to a new development method for industrial autonomous systems.

Improved system robustness is as important for ICT systems as for other technical systems. The computers, sensors and communication links makes up the ship’s ability to observe the environment, determine necessary actions by itself and its ability to call on human backup in situations that the on board systems cannot handle. Also, in case of full system failure, the ICT systems must have enough remaining functionality to allow the operator to locate and rescue the ship. The suggested physical ICT architecture has been described in D4.3. The main features are fully redundant on board data networks for all critical functions, dual redundant satellite communication and an independent Rendezvous Control Unit (RCU) that remains operational even when all other systems fail. The deliverable also lists general requirements to communication channels and other sub-systems.

The maritime intelligent transport system (MITS) architecture that has been suggested as a baseline for further developments of the e-Maritime concept has also been developed further in MUNIN. In the conceptual layer, several definitions of autonomy related concepts have been produced. This includes autonomy levels, voyage phases, concepts for on-board and on-shore systems etc. These are fairly specialized results, but important for future work on unmanned or remotely controlled ships. In the logical layers, the project has produced use cases and scenarios for the MUNIN ship that has been made available on http://www.mits-forum.org/munin/index.htm. This is of limited value if directly used in new projects, but they are valuable as templates for important functionality in this type of ship. Information models have not been dealt with that extensively in MUNIN. The hope was that IMO, IEC and ISO (international organisation involved in the e-navigation standards work) would have progressed further on
the so called S-100 framework for maritime data modelling so that this could be used by MUNIN also. Unfortunately, this has not been the case, so data modelling done in MUNIN is mostly for internal use. The work has been documented in D4.6 but this is probably of limited interest outside the project. The service layer was not a target for MUNIN work and has not received much attention in the project. The transport layer however, has been important and D4.3 goes into some detail on how different communication channels can be used by unmanned ships and how these can be differentiated between in terms of service quality. This is also compared with expected communication requirements from the on-board and on-shore services. Work has also been done on shipboard networks and necessary technology to ensure safe and secure integration between ship and shore. This is documented in international standards as described in the next paragraph.

MUNIN has contributed to development of new IEC standards for shipboard data networks and ship to shore interfaces. IEC 61162-460 has recently been accepted as an international standard and will be published later in 2015. The title of the standard is “Maritime navigation and radiocommunication equipment and systems - Digital interfaces - Part 460: Multiple talker and multiple listeners - Ethernet interconnection - Safety and security”. It contains specifications for building a highly resilient bridge data network and how this can be securely connected to external networks and to shore. The development of the standard was done by working group 6 in IEC TC80, but MUNIN has contributed significantly to the work. MUNIN has also contributed to the developing IEC 62940 standard on “Integrated communication system (ICS) - Operational and performance requirements, methods of testing and required test result”. This is still in committee phase and will not be finished before 2016 or 2017. It contains provisions for design and test of an integrated communication system for multiple communication channels, including proposed protocols for routing ship to shore communication messages. Both these standards are very relevant for future autonomous or remote control ships.

Finally, WP4 has also contributed components to a new and developing methodology for design of industrial autonomous system. This is the main exploitable result for the partner MARINTEK together with its sister companies in the SINTEF group, which will use this in an in-house method developments for this type of systems called Seatonomy. It is expected that industrial autonomous systems will be an important market. The parts of the method developed in MUNIN have been documented in public papers:

WP5: Autonomous Bridge
According to the definition of the autonomous vessel, parts of the operation are autonomously conducted by the vessel in deep sea, while minor parts are either completely transferred to shore or the ship is remotely-operated from there during certain operations. Thus, the nautical tasks that need to be changed to enable unmanned navigation must be identified and the autonomous functionalities needed must be defined, while subsequently these functionalities must be developed. Three prototypes have been
developed with regards to on board ship navigation and applied during several test and dissemination events. The software prototypes are:

- Advanced Sensor Module
- Deep Sea Navigation System (also called Autonomous Navigation System)
  o Incl. COLREG-based Collision Avoidance Module
  o Incl. MSC.1/Circ.1228-based Harsh Weather Operation Module
  o Incl. Strategic Harsh Weather Route Planning Module
- Remote Maneuvering Support Systems

The Advanced Sensor Module (ASM) is active in the autonomous operation mode, but can also be used as assistance system in remote control. The tasks of the ASM are to maintain an automatic lookout for traffic and obstacles as well as lookout for environmental conditions surrounding the vessel. The goal of the ASM is to maintain lookout by all available means so that an unmanned vessel can comply with COLREG, minimize the risk of collision and ensure safe voyage. However, as existing sensors all have individual limitations, the ASM fuses all individual raw sensor data and then extracts the required information from that data base with the help of sensor and feature processors (so called Sensor Fusion Approach) to build a world model around the vessel. Within MUNIN, an ASM processor prototype for the sensor fusion concept has been developed based on Aptomar’s existing SECurus System, focusing especially on small object detection including corresponding sensor and feature processors. The prototype already integrates marine radar, AIS receiver, general nautical data via NMEA as well as electro-optical sensors like daylight and infrared cameras. It can either be connected to live equipment on board vessels or run on data recordings in the lab. This prototype has been partly tested under laboratory conditions, but also several in-situ tests on existing ships have been conducted giving it a TRL status of 4-5.

The Autonomous Navigation System (ANS) is basically only active in the autonomous operation mode. Its task is to navigate the UAS safely from boarding point to boarding point. Besides using existing functionalities of Integrated Bridge Systems, it comprises the tasks Conduct weather routeing, Determine Ship dynamics, Control buoyancy and stability, Avoid collision and Manage alarm and emergencies. Most critical hazards for navigation in deep sea areas are collision and foundering. Thus, the ANS prototype mainly comprises those two functional areas. Safe weather routeing is ensured by anticipatory route optimization using the A*-algorithm and emergency handling procedures, while the collision avoidance algorithm works with a formalized description of COLREG. These functionalities, together with a simple autopilot, have been programmed in a C++-environment and connected to a ship handling simulator for testing and validation giving it a TRL status of 3-4. Furthermore, additional collision avoidance tests have been conducted with the help of a fleet of small in-situ model vessel.

Finally, the Remote Maneuvering Support System (RMSS) serves as an assistance system for the Shore Control Center during the remote operation mode. It is a computer-based system to allow safe autonomous operation for ships controlled largely by shore-side operators. The system provides electronic chart based modules for designing steering sequences for manoeuvring, for monitoring the vessel during manoeuvring operation and for predicting future ship status with respect to her dynamic parameters (position, course, heading, speed course over ground and through water etc.). The RMSS modules substantially support the manoeuvring process to design efficient manoeuvring plans and allow for safe navigation with sufficient reserves during remote-controlled manoeuvring. Core functions are fast-time simulation based prediction capabilities, enabling the operator to “look ahead” and to better sense the ship’s manoeuvring characteristics to foresee potential problems and moreover - react in proper time. Ad proof of concept (TRL status 3) has been conducted with the system in a simulator set-up.
Parts of the conceptual and prototype functionalities can be found in the public papers:

as well as in various parts of the deliverables.

WP6: Autonomous Engine Room

With regards to the engine, again the technical system changes must be identified, which are needed to ensure a safe operation of the engine during the deep-sea voyage in a way, that no physical interference with the engine is needed. In doing so, two prototypes have been developed and presented during test and dissemination events. The software prototypes are:
- Autonomous Engine Monitoring and Control and
- Engine Efficiency System.

The Autonomous Engine Monitoring and Control System (AEMC) is the autonomous controller for the engine room. It monitors and controls the all engine room components and works as a transceiver for the Shore Control Centre. The most important features of the AEMC are autonomous control of the engine room and emergency handling. Both functionalities require direct access to Ship Automation System and additional sensors e.g. IR-cameras, water inrush detection, gas detection and fire detection. Emergency handling contains detection of a failure through monitoring of values. Furthermore it contains the start of countermeasures to avoid damages to ship components. Its prototype is a software module that implements the most important features, the autonomous control of the engine room and the emergency handling, of the Autonomous Engine Monitoring and Control System (AEMC). Offline Data from ship engine simulator is interpreted, thus it is capable of very limited monitoring and failure response actions on defined errors in selected scenarios only. Therefore, it is at a proof of concept status (TRL 3).

The engine efficiency system (EES) connects Key Performance Indicators to the maintenance interaction system with the goal of identifying deteriorating machinery, thus being an important tool for preventive maintenance. The system offers a load sharing application that will ensure that electricity producers run
optimally. In cases where the waste heat recovery system does not cover the electrical load, the load sharing algorithm will automatically dictate which auxiliary engines run to keep the total fuel oil consumption as low as possible and seek to even running hours as much as possible. The system also offers leg based performance and environmental reports that display key performance indicators aggregated from logged data on-board the ship. The prototype compromises of an engine load balancing application that will calculate the optimal running parameters of the engine room’s electrical producers. It will take in to account the electrical need of the ships systems and run the diesel generators and WHR as efficiently as possible in terms of fuel consumption. At the arrival port, the operator can request a leg-based performance report and an environmental report for the sailed leg to analyse. In order to keep engine room components running efficiently, examples of KPI’s intended for preventive maintenance have been implemented in the maintenance scheme and will be presented in the Maintenance Interaction System’s storyboard. The conceptual approach has been proven to be promising together with the AEMC (TRL 3).

Besides the software prototypes, different concepts of for an unmanned engine room have been developed, i.e.
- a general engine redesign as well as
- a maintenance interaction system

The most important points of the new redesigned engine room are the two-stroke low speed turbocharged crosshead Diesel engine with a directly coupled fixed pitch propeller as main propulsion system. Additionally, a pump jet is installed as fall-back solution for the non-redundant main engine. For energy production a waste heat recovery system and three Diesel Generators are installed. Furthermore, the concept specifies plenty of redundancy to ensure the reliability during the deep sea voyage.

The main function for Maintenance Interaction System is to provide maintenance for unmanned engine rooms. Maintenance is the combination of all technical, administrative and managerial actions during the life cycle of the unmanned engine room to retain it in, or restore it to a state in which it can perform the required functions. In particular, the maintenance concept proposes Key Performance Indicators (KPIs) for unmanned engine rooms.

Parts of the conceptual and prototype functionalities can be found in the public papers:

as well as in various parts of the deliverables.

WP7: Shore Control Centre

The Shore Control Centre (SCC) acts as the onshore control and monitoring centre for the autonomously operated unmanned vessel. While primarily focused on monitoring the operational status of the vessel, it also provides the capability to take over direct remote control in extraordinary situations. Thus, the main challenge was to keep situation awareness of the operator appropriately high despite the physical distance between the vessel and the human. This resulted in one software prototype for the Shore Control Centre SCC.

Its Human-Machine-Interface must be developed using decision-making heuristics that compliment an
operator’s ability to obtain and maintain situational awareness and remain “in the loop” in distributed decision-making environments in order to achieve the ultimate goal of safe, unmanned and autonomous shipping. For the prototype, a dashboard system presenting 145 information items organized into nine “information” groups will allow an operator to monitor six vessels. This was linked to several ship handling simulators to allow for a proof of concept during several scenario tests applied. Furthermore, two further concept studies regarding shore control were analysed:
- The conceptual and organisational layout of the SCC and
- Its implications on other stakeholders.

In this respect and assuming a technologically mature state, it was supposed the SCC to monitor a number of 100 ships, six ships per operator. It presumes that the ships will be autonomous most of the time and that (unplanned) operator assistance will only be needed once per 1000 hours. (Planned) operator assistance will always be needed when the vessel is released to, or retrieved from, autonomous operation, as well as in communication with other ships and shore based services. Provisions for advanced assistance by a SCC “captain” and “engineer” for problem solving will also be available. Although the ship is assumed to mainly be under autonomous control, navigating and doing collision avoidance, the SCC has the ability to remote control the ship in several different levels, from minor course changes (by tweaking waypoints on the vessels voyage plan) to complete remote control from a “remote bridge” with much the same facilities as a normal on board bridge.

Furthermore, the implications of a SCC on other maritime stakeholders have been analysed and organizational synergies have been identified. A number of stakeholders, who will have some kind of connection in the future to an established SCC or unmanned autonomous vessels, were interviewed and requested to do qualitative surveys in this task. One important conclusion is that regulatory authorities need to be better informed about emerging technologies and how these will be accounted for in future rules, laws and best practices development. Also, organisational synergies have been identified, e.g. by even automatimg the chain into the port. These should not only further reduce implementing costs, but allow for more efficient emerging e-navigation strategies. Technologies not yet developed remain both an opportunity and a barrier to acceptance of this concept. “Out of the box” thinking must prevail so that further exploration and development of the concept may occur.

Parts of the conceptual and prototype functionalities can be found in the public papers:

as well as in various parts of the deliverables.

WP8: Proof of concept
To allow for testing and validating unmanned vessels, MUNIN has not just developed a concept, but implemented prototypes of the most critical applications and integrated them into a ship-handling simulation-based test-bed.
Intra-Prototype communication is achieved by a web-server and the Advanced Messaging Queue Protocol
AMQP. This set-up also connects the MUNIN prototypes to ship handlings simulators via special linker software that reads and writes to NMEA- or uses vendor-specific interfaces where appropriate. The test-bed allows integrating six different ship-handling simulator and two full SCC operator stations in one scenario, but the set-up is scalable to further participating units, if needed. As the MUNIN-test-bed is directly coupled to the simulators, it can even be integrated in more holistic sea traffic test-beds like the European Maritime Simulator Network of the MONALISA 2.0 project, which would enable testing in close-to-reality traffic situations. Additionally, the modular approach of the prototypes allows adding further elements or prototypes to the test-bed, if they use the MUNIN-specific AMQP-messages.

WP9: Assessment

The objective of the assessment goes beyond the pure technical validation, but is to identify the impacts of the developed concept for an unmanned and autonomous ship and thus to assess what processes and stakeholders are affected in which way by either intended or unintended impacts. All three main dimensions of particular relevance are covered within MUNIN: legal, safety (and security) as well as economic impacts.

The first part of the assessment focussed on the identification and initial qualitative assessment of impacts - both intended and unintended – associated with the individual modules in the MUNIN concept as well as the complete system comprising all modules. To this end an impact matrix assessment was carried out by the MUNIN expert panel in two consecutive rounds following a Delphi-method like approach. Safety & security, economic as well as social and environmental issues are accounted for. Due to the overarching character of the legal & liability issues, these are dealt with individually.

The second part of the assessment focussed on the external perspective on the innovation of an autonomous unmanned vessel and thus obtained a wider perspective. To this end three interrelated aspects were covered:

- Workshops were held to identify critical safety and security hazards from different aspects of unmanned ship operation and carry out a risk assessment of these hazards.
- A questionnaire was sent to several States in order to gather their views on three related areas: social acceptability, technical issues, and political issues.
- A questionnaire was designed to capture the view of maritime stakeholders on the innovation of autonomous ships and key impacts associated therewith.

The last part of the assessment conducted an in-depth analysis of the most important impacts building on the previous assessment results. The financial analysis evaluated if and under which circumstances a MUNIN bulker would be commercially viable. While still associated with a high level of uncertainty - due to the early stage of concept development and the limited scope of the project MUNIN – the results show that an autonomous bulker has a favourable expected present value compared to a reference bulker. In the safety and security analysis the semi-quantitative risk analysis has been refined with more statistical data and used to provide a refined risk assessment. Further identified safety and security benefits have been quantified as far as possible. This forms the basis for an overall safety and security assessment of the unmanned ship compared to corresponding manned ships in the same trade. The legal analysis covers all important points identified following a detailed analysis of key technical results of the MUNIN project: legal issues regarding navigation, manning in the Shore Control Centre (SCC) and engine and maintenance, discusses overall issues of contractual, tort and criminal liability in the context of an unmanned ship, and concludes with an explanation of likely insurance issues arising. The analysis shows that the existing legal framework will require some formal amendments for autonomous ships. However, there are no
fundamental substantive obstacles in law which could not be overcome.

4.1.2 WP10: Future Concepts
The objective of WP10 was to formulate realistic future applications of the MUNIN concept in national and international shipping. This includes high speed and short sea shipping, new approaches in deep sea merchant shipping, application of MUNIN results on manned ships and alternative arrangements of shipping infrastructure services, in particular VTS and SAR. The intention of the WP is to provide other researchers with a good background for what are likely applications of the technology and why. This includes identifying constraints and problem areas more concretely.

WP10 indirectly addresses all of the “beyond state of art” objectives in MUNIN. The purpose of the WP is to analyse the benefits and problems of unmanned ships, many of which are derived from the technological and legal challenges that the other WPs address, and propose alternative business cases for ship autonomy that fits better with the constraints that have to be met.

The MUNIN case ship, the retrofitted Handymax dry bulker, turned out not to be a very likely first application for unmanned ships. The reasons for this have been described in D10.2 and consist of 14 different constraints that need to be addressed for a viable unmanned ship. One main problem is the need for more redundancy than one finds in conventional ships where one large main engine normally propels the ship. This gives optimal fuel efficiency and low capital costs. Also problems related to using heavy fuel oil (HFO) on unmanned ships may increase operational costs in this type of setting as, e.g. Marine Gas Oil (MGO) is between 60 and 100% more expensive than HFO. Thus, particularly with high fuel prices, one need to find business cases where dual propulsion systems and more expensive fuels can be made worthwhile. One obvious cost saver is to make away with the accommodation section altogether. This saves capital costs and reduces energy consumption and maintenance significantly. Another possibility is to go for larger ships with more installed power. This makes lower fuel efficiency in smaller engines less of an issue. Also ships with more complex operational profiles such as short sea or offshore supply may be better economical cases as they already have invested in more complex machinery solutions. Also selecting ships that operate for much of their time in Emission Control Areas (ECA) makes MGO less of a problems as these ships need to cater for stricter emission limits in any case. Also, if it is possible to use LNG, this may solve the cost problem, although at the cost of more ship volume being set aside for LNG tanks. Summarizing the findings in WP10 give an idea of how the future unmanned ship may look like:
- No accommodation section at all.
- Many new technical solutions to avoid need for maintenance under way.
- Fully redundant propulsion and power generation systems.

This points to specialized and purpose built ships, e.g. electrical motors, with LNG tanks and generator sets on deck to save cargo space and simplify maintenance in ports. WP 10 has pointed out four cases that seem to be likely shorter term candidates for autonomous ships:

1. A large container carrier operating between west coast of USA and China without passing channels. These ships are large enough that efficiency loss in dual propulsion is less of a problem and building costs may in fact not be much affected. Much of the voyage is open sea and the operation between only two nations simplifies legal issues. One should run the ship on LNG or pre-processed HFO that do not require
2. A small container shuttle for last mile transport from feeder ports to cities in the vicinity. It may also be used for internal transport in larger ports or similar areas. These can probably be operated with batteries and are low cost enough to allow time for charging while still earning enough to service capital investments. Close to shore will ensure that one has high capacity radio links for advanced remote control in heavy traffic areas. This operates in national waters only and this will simplify regulatory issues.

3. Supply vessels for offshore wind or oil and gas applications. Both platforms and base will have well developed infrastructure for remote control and berthing and this type of vessel already have advanced propulsion systems with dynamic positioning and often diesel-electric systems on board. Again, operation in national waters simplifies regulatory issues.

4. Small short sea vessel to complement traditional feeders with service between terminal or feeder ports and other small ports. Feeders may also be an option, but cost-effectiveness gains may be higher on this alternate traffic that today has significant problems with the cost of new ships. By automating operations, including loading and discharge, significant sums can be saved. This will also allow operation 24 hours a day which is not possible in many ports due to cost of having personnel there during night time.

WP10 does not have any direct exploitation potential in that it tries to look into the future and give some likely scenarios to the public at large. However, it is an important WP for all partners in that it provides a sanity check on the MUNIN concepts and points the way to further research needs and future markets. In this way, it can be said to sum up the project for all that has been involved and tell us where to go now.

S/T progress Anti Collision
The progress made in the area of “Anti Collision” is mainly caused by the interaction of the ASM and the ANS. D5.3 Sensor systems for automated detection explains the process on how the ASM merges and classifies the detected targets from different sensor systems based on a sensor fusion approach. Thereby, features about the surrounding of the vessel are extracted based on predefined models and then correlated amongst themselves and with a-priori information such as sea charts and vessel databases and turned into information about the state of the vessel and the world.

D8.3 In-situ test report on detection sensors then evaluates the proposed ASM approach and its functionalities with regards to object detection under different environmental characteristics in real life applications. Certain results of those tests were negative, but mainly due to insufficient range of the test equipment, which was available on board the vessel. However, given other improved equipment which is available on the marked, it is concluded, that today’s sensors are in general capable to monitor the vicinity of a vessel sufficiently and thus, that it is possible to realize a proper lookout.

S/T progress Autonomous Navigation
In the area of autonomous navigation, the focus lied on solving the two main critical hazards collision and foundering, which has been identified at the main task for an autonomous navigation system in D5.2 Process Map for Autonomous Navigation. D5.4 Autonomous deep sea navigation concept proposes and
Initially tested an approach, how these two functionalities can be handled in a control application. Regarding collision avoidance, the actual traffic situation according to COLREG is analysed based on different object data categories provided by the ASM and a formalized description of the COLREG Part B obligations. Afterwards, generic manoeuvre strategies are executed. Furthermore, the A*-based route finding algorithm proposes MSC.1/Circ. 1228 compliant routes to avoid dangerous weather phenomena minimizing fuel-oil-consumption.

In D5.5 Support system for remote manoeuvring concept an system based on fast time simulation technique for route finding and assistance during remote control operations is described. All those have also been tested in a prototype set-up within the MUNIN simulation test-bed.

S/T progress Efficient operation
The main progress with regard to efficient operations is contained in D6.8 Constant engine efficiency concept. Here, critical key performance indicators for energy efficiency are defined and monitored. The system also offers a load sharing application that will ensure that electricity producers run optimally. In cases where e.g. the waste heat recovery system does not cover the electrical load, the load sharing algorithm will automatically dictate which auxiliary engines run to keep the total fuel oil consumption as low as possible and seek to even running hours as much as possible. As mentioned before, D5.4 Autonomous deep sea navigation concept also looked at the issue of optimal weather routing with regards to fuel oil consumption and not only on the safety criteria.

However, the main drivers for more efficient operations of unmanned vessels are the identified improvements that can be realised due to fewer restrictions on crew welfare and transit speeds. D9.3 Quantitative assessment highlights, that there are additional efficiency gains possible, like e.g. less air resistance and ship weight due to a missing deckhouse or less auxiliary engine load due to missing hotel/life-support systems, which can further improve consumption by up to 5% compared to a manned ship.

S/T progress Improved system robustness
The system robustness is a key factor of the reports D6.2 General technical redesign, D6.5 Information and control specification document and D6.6 Diagnostics information and performance monitoring system specification document.
D6.2 describes the general redesign of the autonomous MUNIN vessel. The redesign has a focus on robust and reliable technologies. Furthermore, a high redundancy of critical system is integrated in the redesign. The only major non-redundant system is the two-stroke Diesel engine including the propeller and rudder. As a fail-to-safe mechanism for the main engine a pump jet is added to the redesign. The pump jet is able to provide propulsion and steer the ship to the next harbour in case of a main propulsion failure. D6.5 and D6.6 are more focused in monitoring and diagnosis. The report D6.6 describes needed diagnosis systems with special focus on the non-redundant main propulsion system. The report is also important for a new and better maintenance strategy which also indirectly increases the system robustness.
D6.5 describes the autonomous engine monitoring and control (AEMC) system which has the major task of monitoring the engine room parts, detects failures before they occur in a critical malfunction and set countermeasures to correct failures. Especially the failure detection algorithm and the release of
Countermeasures increase the system robustness to an acceptable level for an autonomous vessel.

**S/T progress Improved planned maintenance**

The project has performed a technical analysis of the most critical technical systems, namely power generation, propulsion and steering. This was done as a failure mode effects and criticality analysis (FMECA). This has identified various components that a) Need redundancy; b) Need enhanced monitoring to prevent malfunction during voyage; or c) Need to be replaced with less sensitive components. The analysis and the redesign systems have been described in D6.1 Specification document for the technical system of an autonomous vessel and D6.2 General technical system redesign.

One conclusion from this is that an unmanned ship must be constructed from the start with the maintenance restrictions in mind. It is probably not possible to retrofit an existing ship for unmanned operation when the maintenance needs are considered. It will be beneficial if one can avoid as much complicated system components as possible. Examples are ship designs that do not require ballast systems, use of very clean fuels like LNG, diesel electric propulsion with generator sets on deck for rapid replacement when in port etc. Using fuels such as LNG would simplify the fuel processing systems as well as remove the need for scrubbers or other emission reduction technologies. These issues are discussed in more details in deliverable D10.2 New ship designs for autonomous vessels.

It was also from the start recognized that a new maintenance monitoring and management system needed to be implemented in the shore control system. This is discussed under the heading of improved operational procedures. This will also require some new instrumentation and analysis systems. Examples are piston ring and lubrication oil analysis. However, these are mostly applicable to large dual stroke diesel engines and may not be necessary in a multi-redundant diesel-electric system. Again, the need to construct the unmanned ship from bottom up with all consequences of autonomy in mind must be emphasized. Results from these activities are described in deliverables D6.4 System aggregate redesign itinerary-based and maintenance schedule concept, D6.5 Information and control specification document and D6.6 Diagnostics information and performance monitoring system specification document.

**S/T progress Improved interaction between ship and coastal parties**

As laid out in D8.8 Final Report Shore-side Control Centre, the shore-based control system will assist the SCC team to plan for a rendezvous point with the Onboard Control Team (OCT) in preparation for both inbound and outbound port passages. The SCC is designed to receive the pertinent information to check the current status of the ship before embarkation and control handover. VHF communication between the OCT on the ship and the SCC would be established and integrated in safety-oriented control handover procedures.

The overview of the SCC with a complex, socio-technical system could be found in the same deliverable. Furthermore, the SCC needs to interact with the VTS in a coordinated manner. The collaboration formalities between the VTS and SCC have been discussed among the interviewed participants in D7.7 Impact of SOC on other maritime stakeholders report, where the majority concluded that this would be possible but the synergies would highly depend on the evolving concept of SCC. More business shore-based opportunities are also shortly described in D10.3 New business opportunities through autonomous vessels.
S/T progress Remote SAR functions

In order for SAR operations to be successful, D10.4 Interaction between SAR and autonomous vessels concluded, that all vessels must become “vessels of opportunity”. Within the MUNIN concept, an unmanned autonomous vessel could support SAR operations as being a safe haven for victims, employed in systematic and coordinated search patterns and become a service platform for assets employed in SAR activities long distances from shore. As a ship of opportunity, an unmanned autonomous vessel can add eyes and ears within a search area. An autonomous vessel will have sensors that have superior capabilities at night and low visibility. Several autonomous vessels can form tactical formations that will increase SAR search pattern efficiency.

S/T progress Remote operation and cooperative decision support

The design of perceptual and technical layout for the categorized ship information in the shore-based controlled system has been intensively discussed in the D7.3 Technical layout of SCC and D7.5 HMI layout for SCC. Flag-based alarming mechanism and four different modes (autonomous, remote control, fail to safe and manual onboard) are introduced in order to facilitate operators to safely and efficiently complete their task of monitoring and controlling unmanned vessels. Normal operations and alarm situations are discussed in D7.4 Organizational layout of SCC. Remote Manoeuvring Support System (RMSS) prototype was developed to supply operators with the relevant data to better monitor and remotely control the vessel. More details can be found in D5.5 Concept of a support system for remote manoeuvring concept. The organizational layout described the limits to safe operations of a fleet of autonomous ships, such as the manning requirement of the operations department and planning department in the SCC as well as the assumption of the size and scalability of the SCC.

S/T progress Improved operational procedures

The analysis of the technical systems showed that a new system for maintenance monitoring and control needs to be developed. This system should be based on technical condition indicators (TCI), a hierarchical set of performance indicators that can both give a hierarchical view of the current condition of the ship and the future need for maintenance. This will give the operator both an at-a-glance overall condition indication as well as the ability to drill down in lower layers' indicators to determine the root cause for a reduction in performance. The indicators are calculated on board and sent to the SCC with limited bandwidth use. Results from this work is described in deliverable D6.7 Maintenance indicators and maintenance management principles for autonomous engine room. This also covers some of the issues related to the shore side work processes.

The indicators will also cover energy efficiency which is closely related to fuel use and the technical condition of the engine components as well as the operational procedures implemented in the autonomous controller. The operator will see an integrated picture covering both energy efficiency and technical condition. On the top level, the key performance indicators will be separate but on lower levels, they will share many of the same indicators. These issues are also discussed under the heading of “efficient operations”.

The project has not made a complete test with actual ship data, but used a subset of data elements to investigate the feasibility of the concept. Screen displays have been simulated to show the concept to the operators and to get feedback on the ideas.
S/T progress Improved ICT architecture
The project has developed a number of additional components to the maritime intelligent transport system architecture. This contains a more complete domain specification, including classifications of autonomous modes, types of autonomous ships and a functional breakdown for the autonomous ship. The modularization of onboard and onshore functions has also provided a new set of role descriptions for control and operation of autonomous ships. This also includes roles of operators in the shore control centre. Results have been published in public papers as well as in deliverables D4.5 Architecture specification, D4.7 Draft architecture standards and D4.9 Draft Standard.

The initial phase of the project was used to perform an UML based analysis of the unmanned ship operations and its components. This resulted in a set of process descriptions that have been made available on the MUNIN web page as well as on the mits-forum.org web pages. As well as being a critical part of the MUNIN system analysis, this gives a good starting point for other researchers wanting to investigate unmanned ship operation. The procedures and the results are available in deliverables D4.1 Initial scenario description and D4.2 General framework and methodology.

Extensive analysis of data transfer requirements as well as cyber security issues have also been performed. Parts of this work have also been incorporated into a newly published standard and secure bridge networks (IEC 61162-460) and a developing standard for integrated communication systems (IEC 62940). The latter has recently been published as a CDV (Committee Draft for Voting). The general analysis of communication requirements can be found in D4.3 Evaluation of ship to shore communication links.

Studies have also been made on descriptor formats for ship-shore communication that lends itself to analysis of the required quality of service for the different communication channels and services. As most ship networks and data communication systems do not support prioritization of different traffic, this has led to a design using switches and virtual LAN technology to achieve traffic separation. This has been incorporated in IEC 61162-460.

The architecture activities have also led to an emerging design methodology for industrial autonomous systems, in which unmanned ship is an important sub-class. The different components of the architecture have been incorporated into the methodology. Initial ideas have been presented in deliverable D4.2 General framework and methodology and has been presented in public papers as discussed under WP4.

S/T progress Legal and contractual challenges
What has been done with regards to:
The overall architecture of International Law of the Sea, concerning the respective roles of flag, coastal and port States should not require modifications to facilitate the operation of an unmanned ship. It is envisaged that the unmanned ship would be registered under a flag State, and capable of following the general rules of International Law of the Sea. While the exact structure, ownership, management and location of the Shore Control Centre have not been decided, it is also envisaged that it could function under traditional Law of the Sea. This is discussed in D7.2 and D5.1.
On the other hand, a significant number of technical standards currently set under existing conventions would have to be modified. For example, many of the equipment standards under SOLAS by and large relate to manning issues in ships, and would therefore be irrelevant to an unmanned ship. By and large the biggest issue would concern requirements in the Collision Regulations, particularly those concerning the 'human' look out. While it is strongly arguable that the unmanned ship would indeed fulfil, or even surpass, the safety requirements embedded in those standards, clarification would be needed as to whether a formal derogation would be needed. D9.1 and D9.3 provide details about this discussion.

In terms of chartering and management, it is not envisaged that changes would be required under existing Maritime Law. Clarification would however be needed as regards the manning issue, which is part of the warrantee of seaworthiness. Similarly, insurance requirements could be met by the industry, if a good case is made for the safety, commercial viability and reliability of the unmanned ship.

As regards liability issue, the single biggest hurdle will be that of the ship master. Currently the ship master is the focus of liability for a manned ship, and in this absence of this role, the question is how liability would be organised. This question is raised and discussed in D9.3 and suggestions are made as to how to approach it. For example, a breakdown of the various liability issues could be spread out between various types of operators in the SCC, or the person in charge of the SCC could be assimilated to the ship master. Ultimately, this is not believed to be an unsurmountable hurdle, and practice will find a solution if and when it arises.

Potential Impact:
Unmanned vessels can contribute to the aim of a more sustainable maritime transport industry. Especially in Europe, shipping companies have to deal with a demographic change within a highly competitive industry, while at the same time the rising ecological awareness exerts additional pressure on them. The autonomous ship represents a long-term, but comprehensive solution to meet these challenges, as it bears the potential to:
• Reduce operational expenses,
• Reduce environmental impact and
• Attract seagoing professionals.

This shift of nautical and engineering tasks from ship to shore also opens new professional perspectives for mariners that can now remain connected to family, friends and their social life. This can help to attract new, highly qualified professionals for “shore-based seafaring”. Indirectly, this can also further promote sustainable maritime transport. Consequently, the dawn of unmanned vessels can even be classified as a disruptive innovation, meaning an innovation that creates new markets by discovering new categories of customers.

The MUNIN project has principally shown that an autonomous vessel is technically feasible. This is backed up by the financial analysis of MUNIN D9.3 which argues that a MUNIN bulker would be commercially viable under certain circumstances. The added value of the concept relative to a base case “conventionally manned bulker” is determined as the difference between cost savings (reduced expenses for crew, better fuel efficiency) and additional investments and costs (higher initial investments, new shore
and port based services). In a base scenario the MUNIN bulker is found to improve the expected present value by mUSD 7 over a 25-year period compared to the reference bulker. Besides reduced personnel costs, better fuel efficiency due to new ship designs is one of the main drivers here. Given the possibility that unmanned vessels don’t need hotel areas, the fuel consumption of the main engine for the reference bulker could be reduced by up to 5% due to better air resistance and lighter ship weights. Further, as no life-support-system is longer needed, the load of the auxiliary engines will presumably reduce even further by up to 40%, resulting also in a better environmental footprint of shipping. Transferring this fuel into a financial gain is of course assuming that the challenge depicted by MUNIN of autonomous heavy fuel oil operation could be solved in future. But even if that event does not occur, unmanned vessels also bears efficiency potentials for certain niches, like e.g. short sea shipping in emission control areas. Plus, they still offer the possibility for a reduced environmental impact. While still associated with a high level of uncertainty - due to the early stage of concept development and the limited scope of the project MUNIN – the results show that the trend of reducing crewing levels further will quite likely become a reality on many modern ships. This is for one reason in particular: besides cost savings associated with reducing crew levels an autonomous ship brings along the potential to create additional benefits due to changes in ship design.

However, technological development is increasingly influenced by societal acceptance. Thus, an assessment which only relies on the opinion of experts without taking into consideration a wider perspective risks neglecting a crucial factor. Accordingly, as part of MUNIN D9.2 the results of a conducted questionnaire are discussed in detail which aimed to capture the view of maritime stakeholder on the innovation of autonomous ships and key impacts associated therewith. It gives answers to the general attitude towards autonomous ships, covers safety and security aspects as well as social and environmental concerns, illustrates the view on technological aspects as well as main opportunities and challenges associated with autonomous ships. It turns out that respondents have a quite positive view on the innovation of autonomous ships overall and almost 80% expect a first appearance of autonomous ship concepts in merchant shipping within the next 10 years. In doing so, the main opportunities seen are potentials by new ship designs (48%) and transfer of autonomous technologies into manned shipping (44%).

On the contrary, preventing accidents due to technology failures has been perceived as the main challenge by close to 60%. Achieving a high safety level of the concept was ensured by a parallel conducted hazard and risk assessment. The derived risk control options of MUNIN D9.2 have been shown on a qualitative level to be sufficient to make the unmanned ship a feasible concept. Those are:

1. Careful design of SCC and SCC manning as well as training of personnel.
2. Design of on board systems for easy maintenance and accurate monitoring of maintenance state. Must also be fast to repair.
3. Ship should be unmanned at all times.
4. Need to avoid heavy or otherwise dangerous weather – use of weather routing
5. Need good sensor and avoidance systems. Selected systems must also be redundant so that a single failure does not disable critical functions.
6. Ship should be directly controlled in heavy or complex traffic.
7. Need redundant power generation, distribution, propulsion and steering
8. Automated fire extinguishing systems are required in all relevant areas. Note that no crew makes this simpler as areas are smaller and that CO2 can be used more safely.

9. A ship without accommodation section is much easier to secure against stowaways in enclosed spaces.

10. Cybersecurity measures are important, including alternative position estimation based on non-GPS systems. The SCC may be particularly vulnerable. Data links must also have sufficient redundancy.

11. Improved cargo monitoring and planning is required.

In most maritime accidents human errors are a crucial part of the root cause of most maritime accidents. E.g. for collision and foundering scenarios, a decrease of collision and foundering risk by around ten times compared to manned shipping was found to be possible, mainly due to the elimination of fatigue issues. This is of course given a proper operational and robustness testing of the implemented system. As this incident categories collision and foundering accounts for almost 50% of all total losses in the period 2005 to 2014, it clearly represents the category with the highest incident probability. Also, risks from engine and other system breakdown should be lower for unmanned ships if proper redundancy is implemented and improved maintenance and monitoring schemes are followed. Fire and explosion represents a relatively small part of all incidents and with the possibility to use more efficient extinguishing systems in fully enclosed spaces, it is likely that the unmanned ship will be much less risk prone than the manned ship. Finally, risks from cyber-attacks and pirates are issues that cause concern. However, as it should be possible to design ships and systems that have a very high resilience against such attacks and one could assume that unmanned ships are less vulnerable to attacks than manned ships in this context as well.

The second most mentioned challenge is the adjustment need regarding the maritime legal and liability framework. The principal areas concern navigation and manning (the ship master, and SCC crewing): in both these areas, the unmanned ship will significantly alter the practical state of play, with likely legal consequences. Standards in construction, design and equipment of ships will also be concerned. Overall, it appears that the unmanned ship does not pose an unsurmountable substantial obstacle in legal terms. Provided there is reasonable certainty that the unmanned ship can operate at least as safely as a manned ship, in all its functionalities, there is no reason to think that the legal framework cannot be adapted. However, as highlighted in MUNIN D9.3 there will be a high number of issues to resolve, particularly relating to the literal application of relevant law, for example where specific human input or standards are required by applicable conventions (the most obvious example concerns the ‘human’ look out requirement in the Collision Regulations). In terms of liability, this report indicates that the biggest issue will concern the attribution of the existing ship master duties to the relevant and adequate persons involved in the operation of an unmanned ship. It is unclear whether this legal role should be divided between the SCC operators and masters, or attributed in law to a single entity in the SCC. This is an issue which will need to be researched further.

A main rational for autonomous ships is an increase in social sustainability by shifting maritime professions from an on board environment towards land based jobs. This would prevent the fact that mariners are somewhat disconnected from their social environment during the long time periods they spend on sea and accordingly increase the attractiveness of their work environment.

According to the questionnaire conducted, it was consensus that autonomous ships would have a positive impact on the work life balance and increase the attractiveness of jobs in the maritime industry. This assumption was confirmed by the stakeholders involved in the questionnaire. A large majority of three-
quarter agreed that being disconnected from their social environment for long periods of time is a disadvantage of the work of mariners. Almost as strong was the support for the statement that shifting maritime jobs to a shore control centre would influence the work-life balance positively and the attractiveness of the working on board a ship compared to a shore control centre was rated favourable only by one-quarter of all respondents. Interestingly enough though, respondents that did or do work on board of a ship were less inclined to agree that shifting jobs from ship to shore would increase the attractiveness than those without on board experience. Of course it has to be considered that respondents with experience on board knew about the up- and downsides before they decided to work as mariners while respondents with no such experience might have chosen a nautical job, but decided otherwise, potentially due to lack in lack in social contact.

As there was initially no other initiative publicly active on unmanned merchant vessels, dissemination has had a high priority in the MUNIN project to ensure acceptance and knowledge of unmanned ships in general and MUNIN in particular. From the start, a clear and distinctive graphical profile was developed and used in most dissemination material, including brochures, posters, reports and deliverables. Also, the name of the project with the implicit story of Odin’s raven Munin was part of a successful dissemination strategy.

The project established a web page for information dissemination and as a repository of public results. Its hit rate has increased to up to 17,500 hits/month reaching more than 70,000 visitors. The presence on the Internet has also been one of the success factors for MUNIN. More than 5300 hits on Google matches “MUNIN unmanned ship”. This includes web reports from Newsweek, BBC, The Economist, Financial Times and many more.

The project itself has delivered 35 technical reports and specifications that are publicly available. Some of these are intermediate results and of limited interest, but a selection of reports are available for those who are planning to work further on the concept of autonomous merchant ships and industrial autonomous systems. These reports are public available at a repository at the unmanned ship web page, which has been visited more than 1500 times.

The project has printed four brochures and a number of posters and roll/ups for exhibitions and conferences. The industry partners’ stands at main maritime exhibitions have also been used to promote MUNIN. Thus, it successfully managed to implement itself as the major international research project on unmanned vessels. A series of four public workshops on unmanned merchant vessels have been organized with 40-70 participants each. Close contact to the other two major activities going on, the DNV GL’s ReVolt Project and the Rolls-Royce initiative could also be arranged and joint appearances on certain events were arranged. Furthermore, the MUNIN project has been invited two times to Asia to present its result and to search for common approaches towards testing and realisation of unmanned vessels together with local academia and industry. The two exchange events scheduled were:
- 15-17 May 2014, Ai-MAST 2014, Mokpo (Korea)
- 24 June 2015, International Seminar on Practical Use of Maritime Big Data, Tokyo (Japan)

As the project has been a concept study with heavy emphasis on open and wide dissemination of results, the project has also produced a number of scientific papers and conference presentations. 14 of these are
easily found on Google Scholar and have already been cited 35 times. For the scientific partners, universities and research institute, the scientific publication is of great value. It directly contributes to value creation for the partners both in terms of visibility and in publication points. It is in a sense the main exploitable result in addition to the added know-how in the organisations.

List of Websites:
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