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Initials	Author	Organisation	Role
MS	Michael Schmidt	MSoft	Editor
EF	Enrico Fentzahn	MSoft	Contributor
GFA	Guðmundur Freyr Atlason	MKA	Contributor
HR	Harald Rødseth	MRTK	Contributor

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HCB	Hans-Christoph Burmeister	X, with comments	
JAM	Jonas Aamodt Moræus	X	

Disclaimer

Executive summary

Establishing an unmanned engine room on-board a cargo vessel is a tremendous challenge when it comes to safe, reliable and environmentally friendly operations. Within work package six (WP6) of the MUNIN project an approach has been developed.

The present report gives an overview on the research work done in WP6. The conceptual work is summarized and developed prototypes are evaluated. The report concludes with a summary that specifies necessary prospective research work.

List of abbreviations

AEMC	Autonomous Engine Monitoring and Control
AMQP	Advanced Message Queuing Protocol
ASC	Autonomous Ship Controller
CO2	Carbon dioxide
EES	Engine Efficiency System
FMECA	Failure mode, effects and criticality analysis
KPI	Key Performance Indicator
MIS	Maintenance Interaction System
NOx	Mono-nitrogen oxide
RPN	Risk Priority Number
SAS	Ship Automation System
SCC	Shore Control Centre
SFOC	Specific Fuel Oil Consumption
SOx	Sulfur oxide
TRL	Technology Readiness Level
UER	Unmanned Engine Room
WHR	Waste Heat Recovery
WP6	Work package six

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1. Introduction

Work package six deals with the Engine / Automation systems (see Figure 1) and contains four tasks. The first task "System analysis and redesign" analysed and summarised the actual work load of the engine room personnel. Furthermore, the needed maintenance activities and periodical work are listed in the first deliverable "Specification document for the technical system of the autonomous vessel". /1/ Based on these analyses the structural redesign of the engine room was made and adjusted to the need of an autonomous unmanned vessel. This redesign builds the technical base for the following tasks in work package six. /2/

The MUNIN main hypothesis is "Unmanned ship systems can autonomously sail on an Intercontinental voyage at least as safely and efficiently as manned ships". The main hypothesis for the unmanned engine room (UER) is:
"An engine can operate reliably for 500 hours without physical interference from a person in the engine room."/9/

The report is divided into three parts. Starting with an overall concept description of the MUNIN unmanned engine room, its components and the corresponding prototypes, the test results from the final prototype workshop are presented and evaluated. The report concludes with an outlook on further research work and sketches next steps on the way to an unmanned engine room.

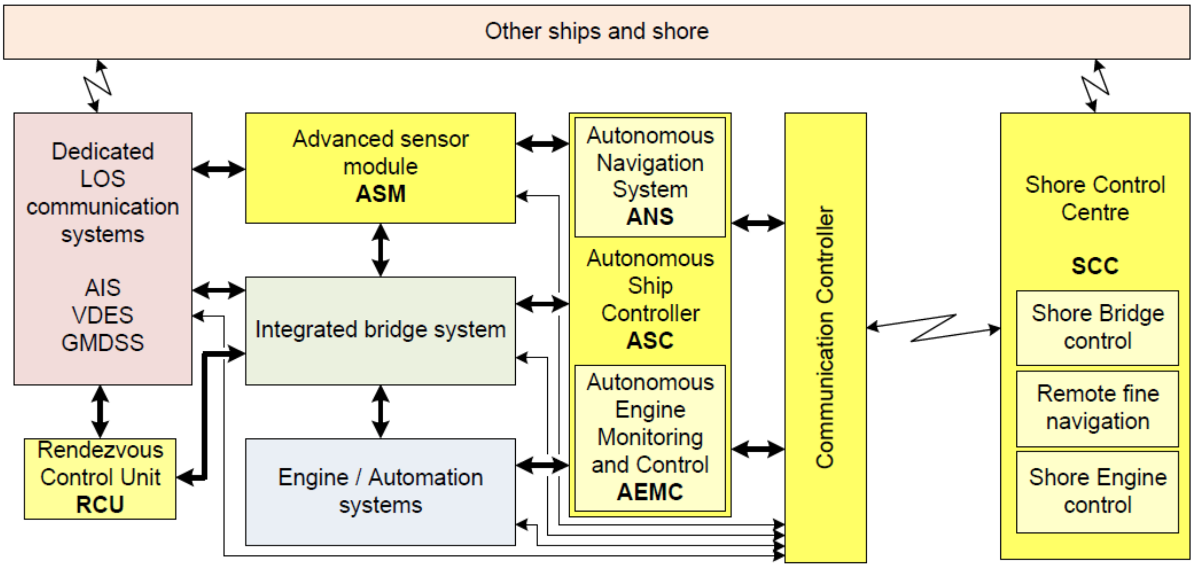

Figure 1: Overview of high level modules /8/

2. Concept overview of Autonomous Engine Room

The engine room houses various machinery and equipment e.g. propulsion engine, gear box and power generators. Their operability is of crucial importance for every engine driven ship, also unmanned vessels. The aim for WP6 was to develop an adequate approach for this sensitive part of the ship system.

After specifying general requirements for unmanned engine room equipment (UER), a conventional engine room was redesigned for autonomous operation in deliverable D6.2 (Schmidt & Wehner, MUNIN D6.1: Specification document for the technical system of an autonomus vessel, 2013) (Schmidt & Wehner, MUNIN D6.2: Specification concept of the general technical system redesign, 2013). 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.

As there is normally no crew aboard during autonomous operation, the unmanned vessel not only has to be equipped with high fidelity automation and various additional sensor systems, it also needs facilities for autonomous operation. In the MUNIN concept these facilities are the added Autonomous Engine Monitoring and Control (AEMC) system and the Autonomous Navigation System (ANS). Both Systems form the Autonomous Ship Controller (ASC).

The AEMC autonomously controls the engine room. It monitors and controls all engine room components and works as a transceiver to the Shore Control Centre (SCC). The most important functions of the AEMC are autonomous control of the engine room and emergency handling. Emergency handling involves detection of a failure by monitoring key values, access to engine automation system (EAS) and additional sensors e.g. IR-cameras, water inrush detection, gas detection and fire detection. Furthermore, emergency handling involves the deployment of countermeasures to avoid damages to ship components. For further details on the AEMC please refer to MUNIN D6.3 "Information cluster concept incl. data set definition" /3/. The structural arrangement of the AEMC is shown in Figure 2.

At normal operation the AEMC system gets input from the Engine Efficiency System (EES) and follows the recommendations from the EES as long as these do not conflict with commands from the ANS. Through this connection to the EES performance is analysed and the AEMC ensures an optimized operation of the electricity producers. /5/

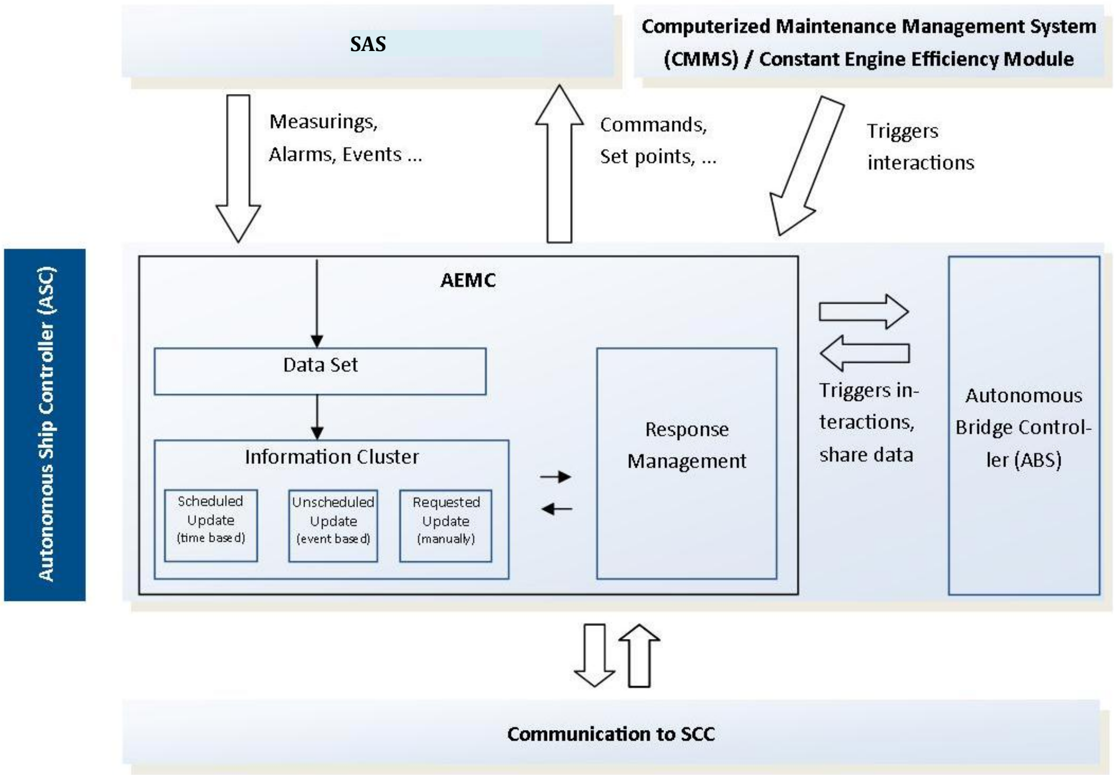

Figure 2: AEMC structural arrangement

The overall maintenance management concept is described in MUNIN D6.7 “Maintenance indicators and maintenance management principles for autonomous engine room” /6/.

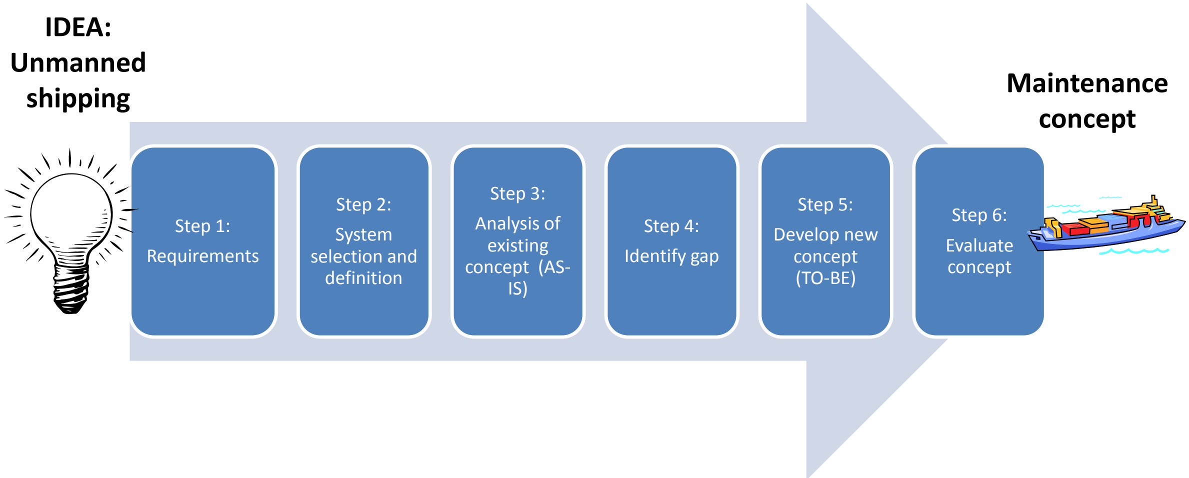

Figure 3 shows how the maintenance concept is developed from requirements to evaluating the concept.

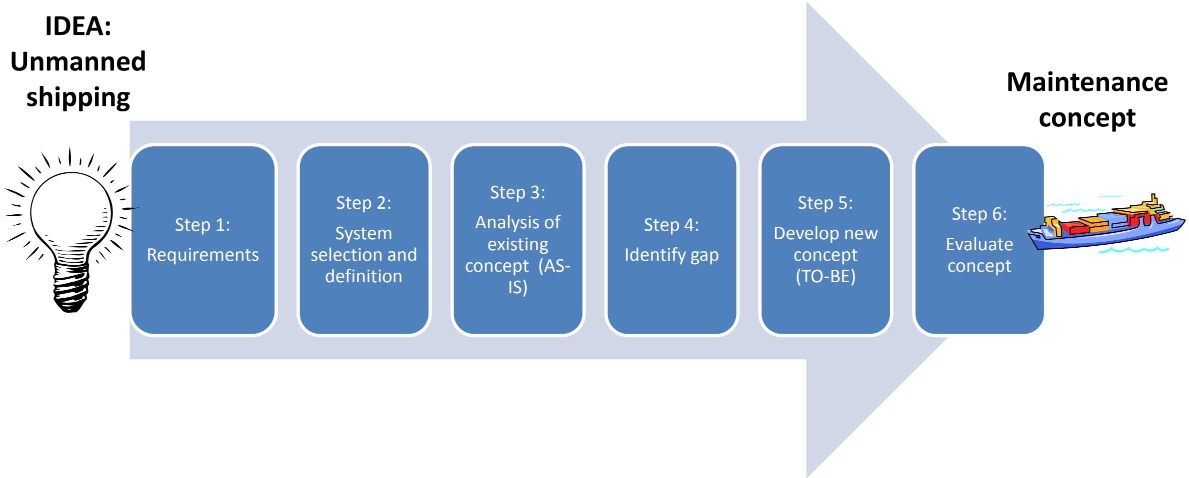

Figure 3 – Structured approach from developing maintenance concept.

The maintenance framework is shown in Figure 4 and the organization layout between operation and maintenance departments for the Shore Control Centre (SCC) is shown in Figure 5.

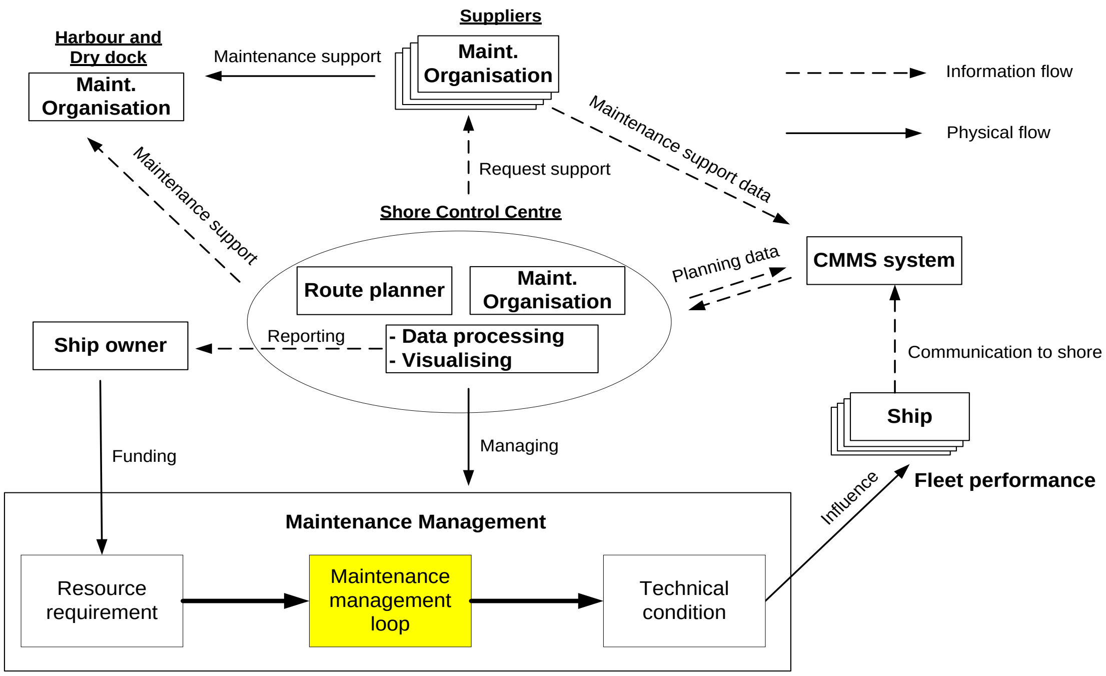

Figure 4 – Maintenance framework

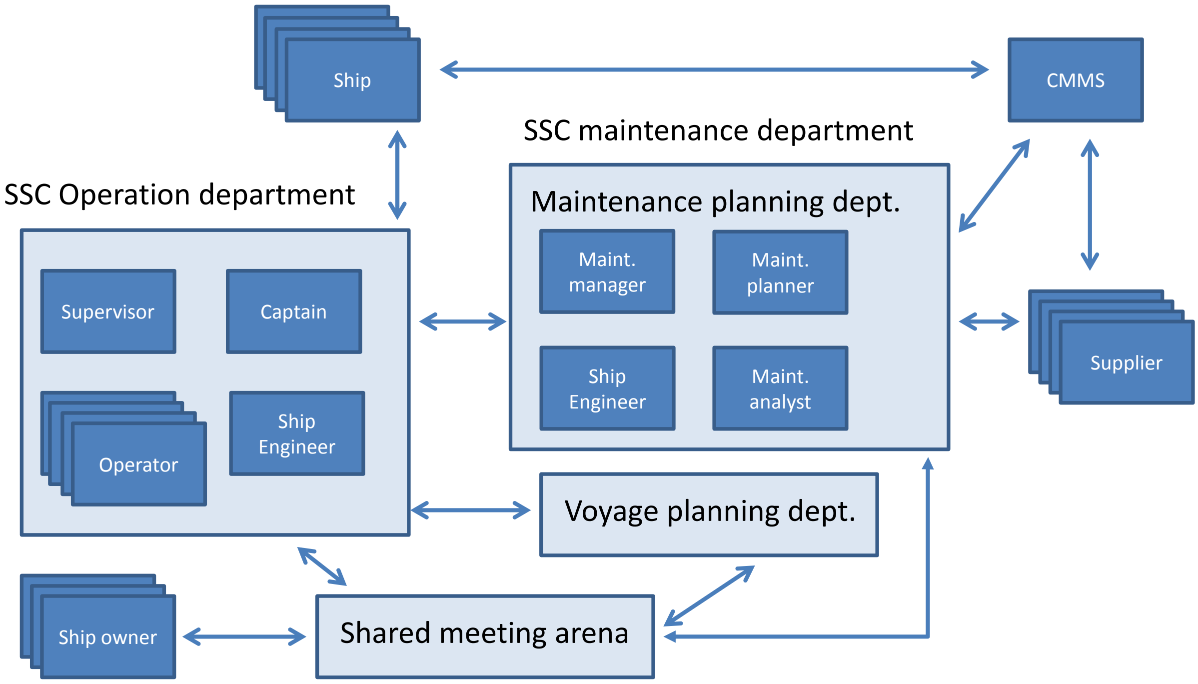

Figure 5 – Organisation layout between operation department and maintenance department

2.1 Autonomous Engine Monitoring and Control

<table>
<tr><td>Name</td><td colspan="2">Autonomous Engine Monitoring and Control (AEMC)</td></tr>
<tr><td colspan="2">Short functional description</td><td>Main restrictions</td></tr>
<tr><td colspan="2">The 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 (SCC).

The most important features of the Autonomous Engine Monitoring and Control System (AEMC) are:

• Autonomous control of the engine room and
• Emergency handling.

Both functionalities require direct access to Ship Automation System (SAS) 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.

For further details on the AEMC please refer to deliverable 6.3 “Information cluster concept incl. data set definition” /3/.</td><td>Safety requirements
Requirements from ship owners
Legal restrictions</td></tr>
<tr><td colspan="3">Prototype implementation</td></tr>
<tr><td colspan="3">The Engine Information 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.

For further details on the AEMC prototype please refer to deliverable 6.5 “Information and control specification document“./7/</td></tr>
<tr><td colspan="3">Module hypothesis</td></tr>
<tr><td colspan="3">An engine can reliably operate for 500hrs without physical interference from a person in the engine room.</td></tr>
</table>

2.2 Engine Efficiency System

Name	
Short functional description	**Main restrictions**
The energy efficiency engine concept is described in deliverable 6.8, as well as the engine efficiency system. The system connects performance KPIs to the MIS 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 WHRS does not cover the electrical load, the load sharing algorithm will automatically dictate which AEs run to keep the total SFOC 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.	Safety requirements Requirements from ship owners
Prototype implementation	
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.	
Module hypothesis	
An engine can reliably operate for 500hrs without physical interference from a person in the engine room.	

2.3 Maintenance Interaction System

<table>
<tr><td>Name</td><td colspan="2">Maintenance Interaction System (MIS)</td></tr>
<tr><td colspan="2">Short functional description</td><td>Main restrictions</td></tr>
<tr><td colspan="2">The main function for Maintenance Interaction System is to provide maintenance for unmanned engine rooms. Maintenance is 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, this maintenance concept provides Key Performance Indicators (KPIs) has been proposed.</td><td>Safety requirements
Requirements from ship owners</td></tr>
<tr><td colspan="3">Prototype implementation</td></tr>
<tr><td colspan="3">The hypothesis is a result on an FMECA process. Based on three failure modes, suitable counter measures where proposed from the WP6 group in order to reduce their risk level down to an acceptable level. The counter measures are furthermore partly demonstrated in story board and in a simulation of carry water overflow.</td></tr>
<tr><td colspan="3">Module hypothesis</td></tr>
<tr><td colspan="3">An engine can reliably operate for 500hrs without physical interference from a person in the engine room.</td></tr>
</table>

3. Test results

3.1 Autonomous Engine Monitoring and Control

Testing		
Sub-Hypothesis	**Test design**	**Result**
The Autonomous Engine Monitoring and Control module is capable of monitoring all observed measuring values of the engine room as good as done by humans on board.	Expert interview with engineers and review concept with regards to their requirements.	Not declined.
The Autonomous Engine Monitoring and Control module is capable of identifying potential errors before the alarm arises based on a knowledge-based database.	Data read from ship engine simulator, limit monitoring and reaction on defined errors in scenarios.	Not declined, algorithm worked fine for the specified scenarios.
The Autonomous Engine Monitoring and Control module can determine effective countermeasures to avoid identified potential errors before they result in a malfunction.	Data read from ship engine simulator, limit monitoring and reaction on defined errors in scenarios.	Not Tested due to missing link.
TRL-Status of AEMC	TRL 3	
Closing remark		

Sub-Hypothesis No. 1 was not declined, as automation level on board nowadays ships is already very high. Autonomous monitoring means to increase the level further and to redesign various systems. This is (already today) technically feasible.

Sub-Hypothesis No. 2 was not declined. The algorithm worked fine for the specified scenarios, but only a very limited number of errors have been evaluated. As the evaluation of different failures might have very similar failure patterns we identify a serious scaling problem here. At this point further research is needed.

Sub-Hypothesis No. 3 was declined, as execution of countermeasures was not implemented. A Simulator interface was not available. As various failures might lead to contrary countermeasures we identify a serious scaling problem here.

Sub-Hypothesis No. 2 (partly) and No. 3 were both not corroborated within the MUNIN project. Both Sub-hypothesis definitely have to be tested again. Within the current project layout this is not possible. For adequate tests a realistic simulator environment or a real ship system must be available. A State-of-the-art Ship Automation System (SAS) should be

connected to simulator or ship system. A bidirectional interface to SAS must be available. Furthermore the knowledge database has to be filled with a large amount of failure patterns and corresponding countermeasures by OEMs and/or other experts.

3.2 Engine Efficiency System

Testing		
Sub-Hypothesis	**Test design**	**Result**
The Energy Efficiency System will monitor emissions of CO2, SOx and NOx and report with at least the same reliability as if reported by an on board crew.	Run main engine and diesel generators and feed prototype with fuel oil consumption measurements, emission reports will be generated then.	Not declined. Emissions are presented in a prefabricated report relevant to the sailed leg.
The Energy Efficiency System can monitor Key Performance Indicators that will alert the Shore Control Centre about poor efficiency in ship propulsion or electrical energy production to improve energy and maintenance management.	Trend Key Performance Indicators and incorporate into a maintenance report structure	Not declined. Demonstrated through storyboard and poster
The Energy Efficiency System intelligently shares the load among diesel generators and waste heat recovery in autonomous mode at least as efficiently as if done manually by an on board crew.	Load sharing prototype will analyse electrical energy demand and recommend to the Autonomous Engine Monitoring and Control System (AEMC) optimal running conditions of electrical energy producers with respect to fuel-oil consumption.	Not declined. Optimal values not sent back to simulator but sent to SCC.
TRL-Status of EES	TRL 3	
Closing remark		
Sub hypothesis No. 1 does not compute any aggregated emission values but rather sends a prefabricated emission and performance reports relative to the MUNIN vessels simulated leg. This is done due to a missing connection to the engine simulator and because the simulation will not run for the duration of the whole leg.		

3.3 Maintenance Interaction System

Testing		
Sub-Hypothesis	**Test design**	**Result**
The MIS ensures that the ship is operational available at an intercontinental voyage for 500hrs without physical intervention with respect to leaking through piston rings.	Risk Priority Number from (RPN) from FMECA: 9 (Yellow) Measure for reducing the RPN to an acceptable level (green): 1. Piston Ring analysis 2. Implementation of Early Warning Indicators & KPIs	Not declined, reduction in the risk matrix from yellow to a green area Demonstration through storyboard and poster
The MIS ensures that the ship is operational availability at intercontinental voyage for 500hrs without physical intervention with respect to carry water overflow.	Risk Priority Number from (RPN) from FMECA: 12 (red) Measure for reducing the RPN to an acceptable level (green): Piston Ring analysis Early Warning Indicators & KPIs New maintenance programme Redesign of engine room	Not declined, reduction in the risk matrix from red to a green area Demonstration through storyboard and poster
The MIS ensures that the AUS is operational availability at intercontinental voyage for 500hrs without physical intervention with respect to lubrication impurities of crank shaft.	Risk Priority Number from (RPN) from FMECA: 12 (red) Measure for reducing the RPN to an acceptable level (green): Oil analysis for diagnosing and prognosis	Not declined, reduction in the risk matrix from red to a green area

TRL-Status of MIS	TRL 2: for storyboard and poster carried out by MRTK and MKA. TRL 3: for demonstrating carry water overflow through simulation carried out by HSW.	
Closing remark		
Based on the risk matrix in the FMECA process and the proposed countermeasures described in test design, the hypothesis is not declined. Furthermore, the demonstration was carried out by MRTK with a storyboard and poster of the maintenance management system. In addition, HSW carried out a demonstration of simulation of carry water overflow which is further linked to the maintenance management system.		

4. Outlook

The development of an unmanned engine room (UER) is definitely a fascinating and challenging task. Within the MUNIN project an auspicious approach towards autonomous engine was developed: the engine room concept was redesigned and various prototypes have been developed in order to verify the approach.

Further research work is needed to develop the approach into a full integrated concept. From today's perspective we recommend the following next steps:

- An Engine Room Simulator that provides a bidirectional interface has to be integrated to experimental setup. The simulator should reflect the specific engine room re-design developed within MUNIN.
- In current MUNIN Project AMQP is used as a temporary communication interface. For further research work a close-to-reality communication framework (Hardware) is to be established.
- Prototypes have to be developed further:
    - AEMC: A large amount of failure patterns and corresponding countermeasures has to be implemented by OEMs and/or other experts into knowledge database.
    - AEMC: A sophisticated response management algorithm has to be developed.
    - EES: Performance and environmental KPI's should be displayed on a dashboard integrated in the SCC. A scheme that defines unacceptable performance KPI's should be developed for all major components in the engine room and monitored as part of the MIS. An algorithm could be developed that predicts the malfunctions based on collected data.
    - MIS: A fully developed FMECA in the design stage in order to analyse suitable maintenance tasks based on the Reliability Centred Maintenance (RCM) method. Furthermore, the maintenance organisation with organisation layout and KPIs should develop an overall maintenance concept inspired by Total Preventive Maintenance and at the same time aligned with the new ISO 55 000 standards within Asset Management.
- A Ship Automation System (SAS) has to be integrated to experimental setup.
- Prototype migration from PC to hardware used in maritime environment e.g. MPC, EPC or PLC.
- Integration of real Hardware systems (e.g. Pumps, Separators) for Hardware-in-the-Loop (HIL) Tests.

- The legal aspects of an UER have not been taken into consideration within MUNIN. As these aspects might be of vital importance when finally realising the UER concept, they should be investigated within the next project phase.

The outcomes of the MUNIN project, regarding UER, are to be summarized as very promising. A UER is technically feasible! The approach developed, should be pursued through further research work.

References

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