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Disclaimer

Executive summary

The technical layout of the Shore Control Centre (SCC) has been presented in Deliverable 7.3 "Technical layout of SOC*"/1/ and the organizational layout of the system has been presented in Deliverable 7.4 "Organizational lay-out of SOC" /2/. Most of the HMI considered in these deliverables have been implemented in Work Package 8 for demonstrations under typical interactive scenarios for the unmanned ship and the SCC. The main hypothesis regarding the successful implementation of the HMI within the SCC was that "*the Shore Control Centre operator will be able to monitor and control 6 unmanned vessels at the same time*". In order to address this hypothesis, a series of quasi-experimental data collection sessions were undertaken.

This report contains results from tests of both the SCC and the remote manouvering system. Tests of the SCC were mostly successful and show that the hypothesis cannot be declined. However, the SCC is a highly complex entity and more research is needed to finally develop a system that can be used in a real life scenario. The tests of the remote manouvering support function were not fully sucessful.

This deliverable finalizes the Shore Control Centre (SCC) of an unmanned ship system in the view of the results of the proof of concept.

* *The SCC was previously called Shore Operations Centre (SOC)*

List of abbreviations

AEMC	Autonomous Engine Monitoring and Control
AIS	Automatic Identification System
ANS	Autonomous Navigation System
ASC	Autonomous Ship Controller
HMI	Human-Machine-Interface
OCT	Onboard Control Team
RMSS	Remote Manoeuvring Support System
SA	Situation Awareness
SOC	Shore Operations Centre
SCC	Shore Control Centre
TRL	Technology Readiness Levels
VTS	Vessel Traffic Services

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1 Introduction

Technologies for unmanned and autonomous vehicle operations have existed for many years and are becoming more popular in the maritime domain. However, keeping unmanned and autonomous ships safely operating without hands-on maintenance and bridge personnel on board for extended periods of time poses many unknown challenges. Autonomous systems have to coexist, interact and communicate with manned systems and the environment around it. Autonomous operations require programmed voyage planning, navigation and collision avoidance systems, which must be continuously monitored by a Shore Control Centre (SCC). The onboard system will consider The International Regulations for Avoiding Collisions at Sea (COLREGS) in its different implementations for good or restricted visibility, and publish its intentions to other federates. The SCC is linked to the ship using whatever communication technologies are available (e.g. GSM, WiMax, VHF or satellite). The SCC plans and uploads voyage data to the unmanned ship and monitors a ship that employs onboard an Autonomous Ship Controller (ASC) during the voyage.

The ASC is primarily composed of an Autonomous Navigation System (ANS) and Autonomous Engine and Monitoring and Control (AEMC). They will need to make navigation decisions and send pertinent engine and navigational data to the SCC based on input from sensors and comparisons to preprogrammed voyage parameters. The SCC operator must be able to quickly identify operational abnormalities, unexpected threats and errors quickly and efficiently in a highly automated context and then communicate this situation to other stakeholders in the SCC. Thus, the Human-Machine-Interface (HMI) 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.

2 Concept overview of SCC

The Shore Control Center is a new entity in the shipping domain. A SCC could control one or several ships. One might imagine SCCs as either official entities coupled to ports, or VTS centers; or as new business opportunities for master mariners looking for new jobs closer to home and family. A SCC could be set up by a traditional ship management company to control his or her fleet of ships, or by a group of captains and engineers, plus a group of pilots setting up an SCC specializing in navigation a particularity difficult area. A SCC could be in control of a ship during the whole voyage, or only during part of the voyage. For instance a chain of SCCs around the globe could alternate in controlling a ship always making sure the center in control had daylight hours, to avoid cumbersome night shifts with increased risk of accidents. Figure 1 provides a conceptual overview of this complex, socio-technical system.

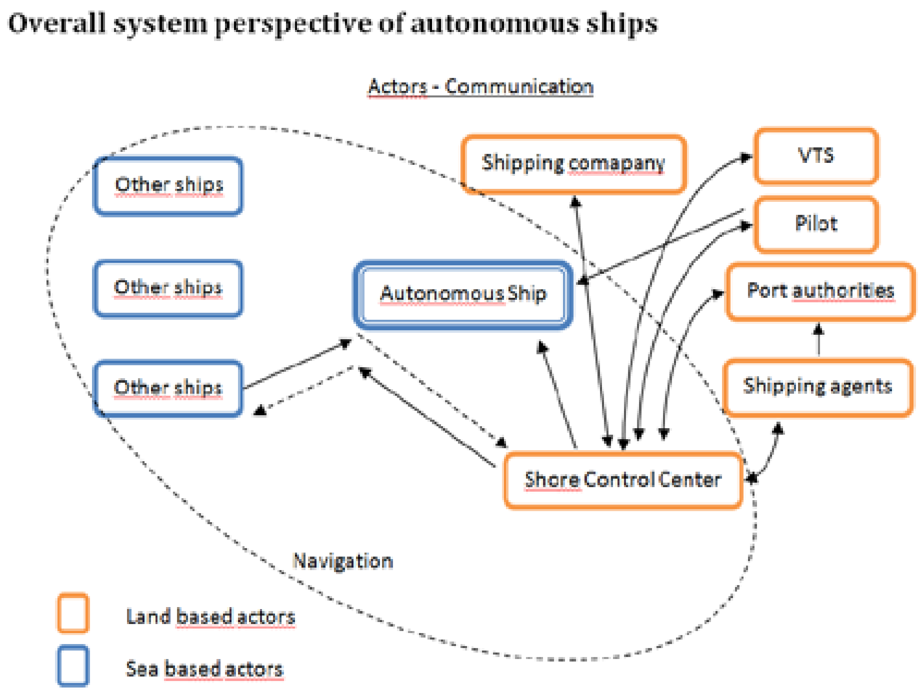

Figure 1: Overview of the Shore Control Center with a complex, socio-technical system.

The operators are the backbone of the SCC. In order to assess the potential demands upon an operator, six nautical officers with a broad range of sea-going experiences and discipline expertise were recruited to contribute to the concept of developing the human-machine interfaces necessary for the SCC concept. In all, 145 information items were identified and organized into nine ¨information¨ groups and were displayed via the SCC HMI.

Within this MUNIN SCC concept, each operator is required to monitor six unmanned vessels via a monitoring and controlling workstation. Each workstation is comprised of six displays which monitors critical elements of the system (see Figure 2). This information cluster includes a customized, vessel specific "dashboard", electronic sea chart, conning display, radar screen and weather chart. Also included in this dislpay bank is a near real-time dashboard display of all the vessels under the operator's control.

The heart of the HMI concept is the HMI dashboard that monitors the status of each vessel (see Figure 3). During most of an intercontinental voyage ships are autonomously controlled by their on-board computerized system and regularly send information to the SCC operator for monitoring purposes. One SCC operator can check the overall status of all six vessels by cycling through each of the six dashboards. On the top "layer" of each dashboard there are nine information panels an operator can explore and monitor specific information about various control processes. Each information panel in the dashboard will have a coloured flag as the top indicator: Green, Yellow or Red. If everything is operating normally (within pre-described operational envelopes) or there is no impending threat, then all nine top flags in the dashboards should be green. If some values on a ship diverge from the pre-set threshold and the autonomous ship controller is incapable of correcting, it will call for help by sending other flags to the SCC to alert the operator of an abnormality. Yellow stands for a non-critical situation that might not require immediate operator intervention but only the operator's attention and verification. A red flag indicates a critical situation within a certain operational category. In Figure 3, the category panel "Sailing", ¨Observations¨and ¨Security¨ indicate Red Flags, which requires the operator to investigate and take corrective actions immediately. The circle rings beside the dashboard displays which modes the autonomous vessel is operating (i.e., under autonomous control, under SCC's remote control, fail-to-safe mode or manual control onboard).

Figure 2: The operator's workstation.

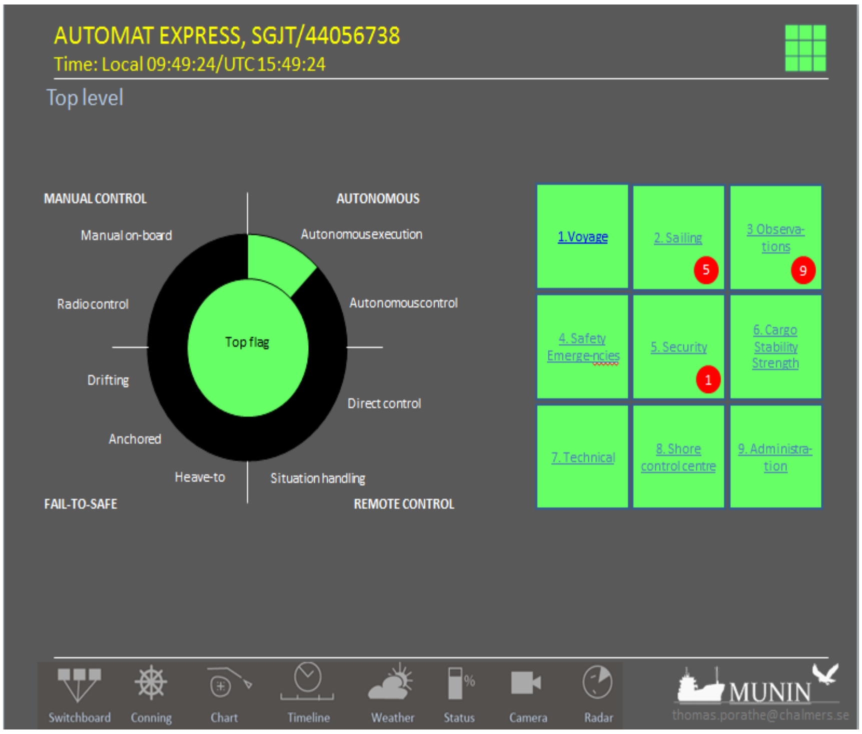

Figure 3: Individual vessel HMI dashboard. /1/

Though operators who are assumed to have navigational background are the backbones of the SCC, they are not the only actors. For example, when a Red Flag is presented the operator can silence the alarm, investigate and cope with the situation by taking advantages of existing workstation-based displays and controls or can request help from the SCC Supervisor. The task of organizing the operator's workload, for example by reallocating resources within the SCC, is the responsibility of the supervisor. It is the supervisor's job to call upon two other SCC actors, if necessary, such as the SCC captain and/or engineer. Figure 4 depicts the SCC hierarchy.

The captain is assumed to be the head of the division and is the person we are assuming is legally responsible for the activities of each vessel under the SCC command, just as a captain on a conventional vessel. When it requires navigational operation from the SCC or handover procedures between the SCC and the team that would board the vessel to take control outbound or inbound from port (be reminded that the MUNIN concept is unmanned, autonomous during deep sea legs of the voyage and the near shore control is done by a pilot in a more traditional manner), it is expected that the captain and the operator in charge will go into the "situation handling room" to conduct precise remote ship handling via Remote Manoeuvring Support System (RMSS) from the SCC.

If it comes to technical issues, the experienced and licensed ship engineer can become another resource for the operator to provide knowledge and experience to look into problems of the on board equipment. In all of these tasks, once collaborating with the captain and engineer, the operator is supposed to assist them with providing pertinent information obtained during the monitoring phases; essentially getting these actors "into the loop" as quickly as possible.

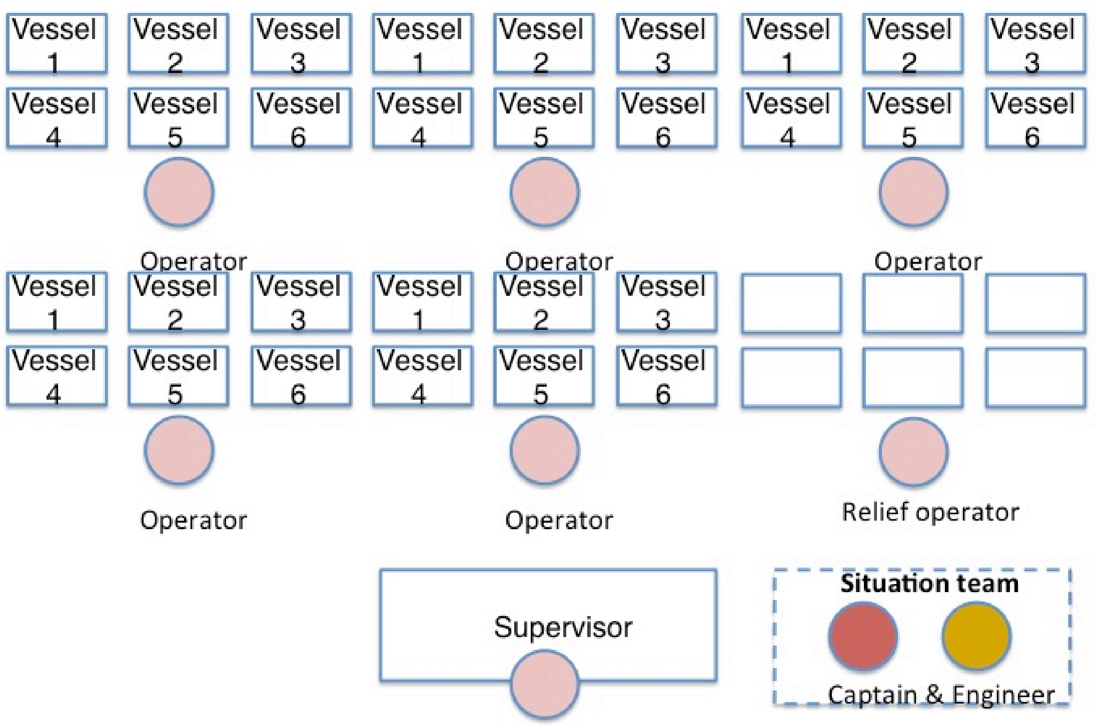

Figure 4: Shore Control Centre Organization /1/

Situation Awareness (SA) is the primary construct used to assess the effectiveness of the proposed HMI. Endsley /4/ defines SA informally and intuitively as “knowing what’s going on” and, more formally, as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (p. 36). SA has become a widely used construct within the human factors domain. Research into SA and its measurement approach have supported the development of advanced information displays, the design of automated systems, information fusion algorithms, and new training approaches for supporting individuals and teams /5/.

Bainbridge /6/ proposed that introducing automation into the monitoring and decision-making process seemed to function best when the workload was light and the task was routine. However, when the automation requires handling of a novel or infrequently occurring events, the operator’s workload may increase with automation, particularly when necessary information has not been considered in the operator’s current state of SA. This is what she described as the “irony of automation”. While mental overload can influence negatively an operator’s performance when unexpected automation failures occur, mental underload can also lead to performance degradation, attention lapses and errors occur /7//8/. The current concept of autonomous unmanned vessels aims for the deployment of state of the art sensing technologies and ad hoc artificial intelligence for automatic collision avoidance and optimization of voyage plan for a given weather forecast during intercontinental voyage, so there is an assumption that if all goes according to plan the SCC operator does nothing but monitor the whole day.

The main hypothesis regarding the successful implementation of the HMI within the SCC was that "t*he Shore Control Centre operator will be able to monitor and control* six unmanned vessels at the same time". In order to address this hypothesis, a series of quasi-experimental data collection sessions were undertaken. These occurred over three occasions. Two of these occasions were at the Simulation Centre in Warnemünde, Germany (September 2-3, 2014 and February 18-20, 2015). These findings are reported in MacKinnon et al. /9/ and Man et al. /10/. These data collection sessions used various scenarios, questionnaires and post-experiment interviews to assess participants’ experiences with the HMI. The overall purpose was to establish if the proposed HMI concept was suitable for an individual operator to manage singular events associated with one identified vessel. These scenarios are described as:

- Deep-sea navigation: A target ship fulfills its collision regulations (COLREG) obligation and own unmanned ship is to give-way; the SCC operator receives the notification from the HMI dashboard with corresponding flags and COLREG-compliant maneuvers from the automated system. The operator needs to keep monitoring automated evasive maneuvers until the situation has been resolved.

- Deep-sea navigation: A target ship does not fulfill its COLREG obligations; the operator receives the notification with red flag and should assess the information with the supervisor. Remote control of the own unmanned vessel should be executed when appropriate.
- Engine problem-Pulp injection failure: The SCC operator is informed of a yellow alarm message that a malfunction of the injection pump has occurred. He needs to acknowledge the information and involve the situation handling team to analyze the problem. The SCC engineer should then analyze the malfunction, plan the maintenance, and give a recommendation to the captain. The captain should make the final decision and inform the operator to take corresponding actions.
- Engine problem – Carry water overflow: The flow is almost the same as the previous except the problem is that a "carry water overflow" occurred in engine.
- Precise maneuvering: The operator and captain need to co-investigate the ship's current state. The operator needs to assist the captain to plan for a rendezvous with the Onboard Control Team (OCT) in preparation for an inbound port approach. The captain needs to provide and confirm information via VHF such as ETA and rendezvous position to the OCT. Followed by maneuvering the vessel through the channel in the situation handling room (with assistance from the operator).
- Crew change: This scenario will be carried out immediately after the scenario ”precise maneuvering". The unmanned vessel is readied for boarding. The boarding team (essentially a pilot) remains in contact with the SCC captain. After embarkation, the SCC must confirm with the pilot is ready to assume full control.

Sub-hypothesis 2, ¨*One operator can monitor six ships with adequate control, situation awareness and workload even if two events occur at the same time*¨ required a third data collection session which was completed at Chalmers University, May 19-21, 2015. The need for the data tests developed during the project and was in addition to the planned project activities. These scenarios were designed to expose the participant to multiple parallel events, such as handling ghost alarm, deviation alarm, unidentified object alarm etc., generally involving more than one vessel. A secondary task (distraction task) was included and involved typical administrative events, such as shore-based VHF calls. The operator was required to prioritize the tasks to ensure the safety of the monitored unmanned vessels. The overall aim was to evaluate the operator's parallel processing performances using the concept HMI. The following figure describes the six scenario matrix. Performance measures included time history analyses, workload measurements and post-experiment questionnaire. The block of 6 flags for each ship represents the collection of possible events, i.e. red flag alert or yellow flag alert.

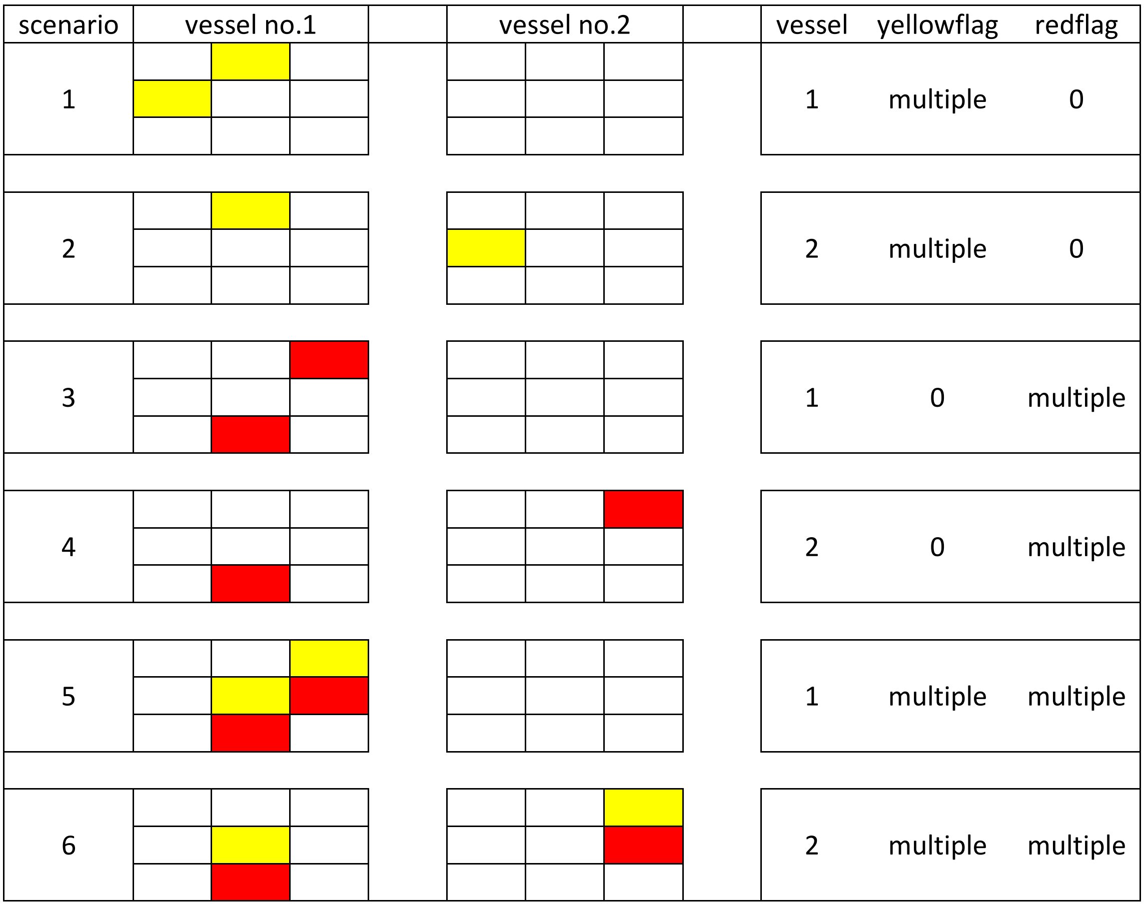

Figure 5: Alerts arrangement in the pressure test

The following two sections give a brief overview of the modules used during the tests. More details can be found in deliverables /1/, /3/ and /15/.

2.1 Shore Control Centre

<table>
<tr><td>Name</td><td colspan="2">Shore Control Center HMI</td></tr>
<tr><td colspan="2">Short functional descripion</td><td>Main restrictions</td></tr>
<tr><td colspan="2">The Human-Machine-Interface (HMI) 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. /1/</td><td>COLREG
STCW</td></tr>
<tr><td colspan="3">Prototype implementation</td></tr>
<tr><td colspan="3">A dashboard system presenting 145 information items organized into nine ¨information¨ groups will allow an operator to monitor six vessels /3/.</td></tr>
<tr><td colspan="3">Module hypothesis</td></tr>
<tr><td colspan="3">The Shore Control Centre operator will be able to monitor and control six unmanned vessels at the same time.</td></tr>
</table>

2.2 Remote Maneuvering Support System

Name	Remote Maneuvering Support System
Short functional descripion	**Main restrictions**
The *Remote Manoeuvring Support System* (RMSS) is a computer-based system to allow safe autonomous operation for ships controlled largely by shore-side operators.	Hydrodynamic model Integrity of input data
Prototype implementation	
The system provides electornic 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. Furthermore a separate RMSS – based module supports the DSNS for situation assessment with respect to risk of collision and decision support by visualising situation adapted limits to take action to avoid a collision at the latest.	
Module hypothesis	
By use of the Remote Manoeuvring Support System, the operator in the Shore Control Centre's situation room can foresee the vessels track and the system assists for safe, efficient and exact manoeuvring (with two seconds satellite latency[1]). Furthermore, pre-planned manoeuvre plans serve as a basis for complex combined manoeuvres in unknown vicinity.	

[1] This latency issue is not addressed within this scenario but will be evaluated out of the project

3 Legal considerations

The investigation in Delieverable 7.7 has revealed that there is a need to inform and prepare the stakeholders, organizations and its employees regarding the changes that may occur in the deployment of the SCC in shipping through unmanned, autonomous vessels.

Many obstacles remain to be solved and initially it is up to the authorities to start addressing the legal issues within the domain to allow development to take place in a broader manner – the possibilities to achieve different types of synergies with current stakeholder groups.

4 Test results

4.1 Shore Control Centre

Testing		
Sub-Hypothesis	**Test design**	**Result**
Operators will have adequate control, situation awareness and workload to perform necessary actions to disembark onboard control teams and set the ship in autonomous execution under normal conditions.	Scenario-based, questionnaires, post-experiment debriefing	Not declined.
One operator can monitor six ships with adequate control, situation awareness and workload even if two events occur at the same time.	Scenario-based, questionnaires, post-experiment debriefing	Inconclusive due to limited data analysis (provisionally not declined).
One operator will have enough time to get into the loop with adequate situation awareness for sudden direct control and evasive maneuvers, at e.g. 4 NM target distance.	Scenario-based, questionnaires, post-experiment debriefing	Not declined.
Situation awareness, workload and time to get into the loop are adequate for solving the engine malfunction and to change voyage plans.	Scenario-based, questionnaires, post-experiment debriefing	Not declined.
Operator will have adequate control and situation awareness to perform necessary actions to embark onboard control team and prepare ship for manual control under normal conditions.	Scenario-based, questionnaires, post-experiment debriefing	Not declined.
TRL-Status of HMI SCC	**TRL 3**	
Closing remark		
Although some technical limitations (some software modules were not fully developed or implemented during the testing periods) in the test system might have impacted		

upon operator/team performance and decision-making, researchers within the project remain confident that the HMI implemented within the SCC contributed to the necessary attainment of situation awareness and allowed SCC members to achieve a workload and task performance that allowed safe monitoring of six autonomous, unmanned vessels. In general, all proposed directional hypotheses confirm these observations.

In the tests completed at Chalmers (May 19 -21 2015) participants' evaluations of the dynamic situations over ten dimensions were collected and calculated. The following Figure 6 reveals some significant preliminary results from the test. The highest score is on the evaluation of the concentration while the lowest is on the judgment of the variable factors in the scenarios. In general, the participants performed well in solving the parallel tasks. However, results also suggest that when attending to parellel events increased attentional demand was required by the operators even though they believed there were not ”too” many disturbing factors within the scenario. The qualitative debriefing confirmed the quantitive data that generally with their navigational experience in real life, the participants evoked reasonable strategies to prioritize their tasks, to reduce the complexity because of the parallel events and try to make the situation manageable. ”Familarity” scored relatively high, demonstrating perhaps the participants' ability to quickly learn how to monitor and respond to the emerging alarms in within the presented scenarios. This suggests that parallel processing demands allowed for obtaining situation awareness and controlling of the situation. However, it may not eliminate all risk of overloading an operator in more complex events. Further testing examining increase strain, bottlenecking, cognitive tunnelling and biases due to the highly automated environment is required. Future work is needed to investigate how an opeartor's parallel processing capabilities are related to the training, stressors, working protocols/regulations in the SCC as well as how HMI can support operators to ease the produres and reduce complexities with its decision support capabilities.

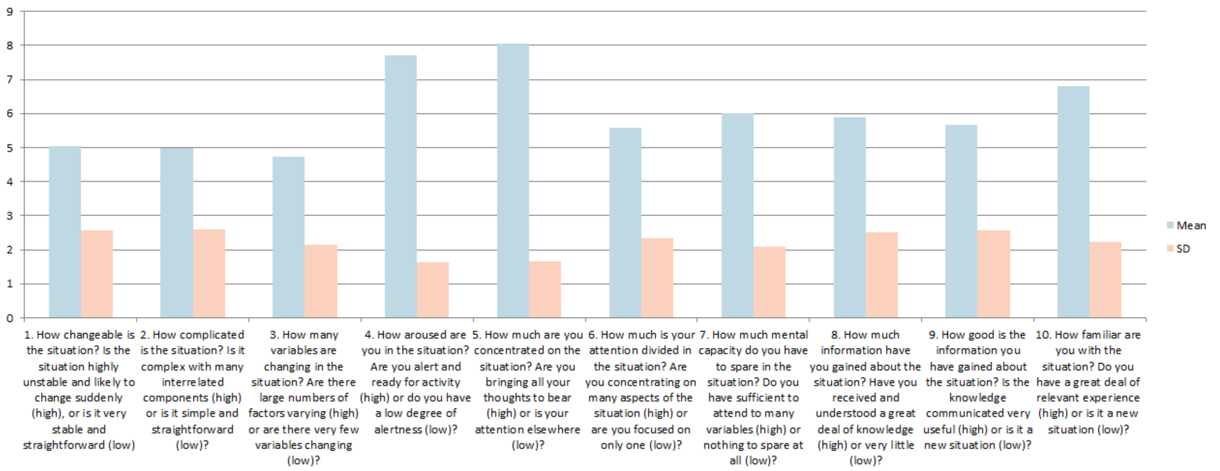

Figure 6: Results from Situation Awareness Rating Questionnaire /16/

The findings from all these tests suggest that the SCC prototype is a typical application within an exceedingly complex distributed automated systems, which should not only organize the technology around the human's needs when they are not "situated", but also focus on how different parts of system could work as a whole in the context from a genuine system perspective.

4.2 Remote Maneuvering Support System

<table>
<tr><td colspan="3">Testing</td></tr>
<tr><td>Sub-Hypothesis</td><td>Test design</td><td>Result</td></tr>
<tr><td>By use of the Remote Manoeuvring Support System, the operator in the Shore Control Centre's situation room can foresee the vessels track and the system assists for safe, efficient and exact manoeuvring (with 2 seconds satellite latency [2]). Furthermore, pre-planned manoeuvre plans serve as a basis for complex combined manoeuvres in unknown vicinity.</td><td>Show manual remote control of ship when doing precise manoeuvres, e.g. for crew pick-up:
- Measure need for communication.
o Manoeuvre pre-planning for upcoming river approach
o Situation handling in confined waters
o Drop anchor for crew embarkation
- Measurements and objectives
o Feasibility demonstration
- Latency investigation on manoeuvring with data delay[3]</td><td>declined</td></tr>
<tr><td>TRL-Status of RMSS</td><td colspan="2">TRL 3</td></tr>
<tr><td colspan="3">Closing remark
Fast Time Simulation based predictions of the RMSS supports planning, conduction and monitoring of safe and efficient steering of unmanned ships. Successful tests were demonstrated with experienced navigators. It is assumed that presently existing manoeuvring experience may reduce corresponding to the introduction of autonmous shipping in practice. The hypothesis was declined mainly due to the fact that the operators did not get proper familiarization with the ship's manoeuvring capabilities and limited functions provided by the RMSS. The RMSS could include more straight-forward and user-centric simulation techniques to develop a 3D simulation environment to mediate the operator’s sense of being there onboard for safety and efficiency improvement of the whole system.</td></tr>
</table>

[2] This latency issue is not addressed within this scenario but will be evaluated out of the project

[3] There is a natural delay of approx. 2 seconds when remotely steering the simulated vessel due to the on Hz update rate of prototypes and simulation process

5 Outlook

The main hypothesis regarding the successful implementation of the HMI within the SCC was that "*the Shore Control Centre operator will be able to monitor and control six unmanned vessels at the same time*". In order to address this hypothesis and a subsequent series of sub-hypotheses, a series of quasi-experimental data collection sessions were undertaken. This evaluation methodology was chosen to test proof of concept from the perspective of usability, acceptability and cognitive performance of the SCC operators based on their behaviors during the trials. In general the supervisory monitoring system in the SCC provided the essential information to support the SCC operator to monitor and control unmanned ships under various scenarios. The operator had to get ¨into-the-loop¨ through obtaining and maintaining situation awareness with a complex socio-technical system. The findings from these tests suggest that the SCC prototype is a typical application of exceedingly complex distributed automated systems, which should not only organize the technology around the human's needs when they are not "situated", but also focus on how different parts of system could work as a whole in the context from a genuine system perspective. Although it remains uncertain about how technologies supporting autonomous, unmanned vessels will emerge, it is clear that a user-centred design will be critical to develop the shore support systems necessary for safe passage of these vessels.

The remote maneuvring support system tests were not fully satisfactory but it is partially because it takes time for the operators to get familiar with the remote maneuvring sytem, while the system itself in the future could integrated with more 3D simulation technologies to mediate the operator's sense of being there onboard for the improvement of the whole system performance.

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