COMMAND AND CONTROL OF UNMANNED VESSELS: KEEPING SHORE BASED OPERATORS IN-THE-LOOP

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ABSTRACT

Future developments specific to the sustainability of the global shipping and transportation industries need to be revolutionary; whether pressured by economic survival or a result of a natural evolution driven by socio-technical realities. Concepts regarding E-navigation and unmanned vessels are only several technological solutions away from operational realities. Conventional thinking suggests that we augment operator decision making with artificially intelligent support systems. Whether these technologies keep the operator "in-the-loop" or diminish overall situation awareness remains to be seen and is dependent upon the quality and robustness of the Human-Machine-Interface (HMI) to monitor and control the automation systems. Automation of a control system, notwithstanding best of the developer(s)' intentions, is not fail-proof. A sudden failure of a highly complex system, whose "artificial intelligence" is not transparent to the operator, may prove beyond the cognitive means of a highly stressed (cognitive overloaded) operator to troubleshoot the situation and recover on time. This paper examines the state of operator situation awareness in monitoring several vessels as part of a Shore-based Control Centre, the hub of an autonomous, unmanned vessel concept.

1. INTRODUCTION

Maritime transport within the European Union faces challenges such as significant increases in transport volumes, more demanding legislative and best-practices requirements and a possible shortage of seafarers. The concept of the autonomous unmanned ship could be a solution to overcome these challenges. It allows for more efficient and competitive ship operations and increases the environmental performance of vessels. Furthermore the shore based control approach offers the seafaring vocation opportunities to become more socially sustainable by reducing the time seafarers spend away from their homes.

Technologies for unmanned and autonomous vehicle operations have existed for many years, but keeping unmanned and autonomous ships safely running without maintenance and service personnel on board for days and weeks poses many unknown challenges. However, these are technical issues that may be addressed as technologies evolve in the future and should not be perceived as a barrier to exploring such transportation constructs.

The Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project is a collaborative research project, co-funded by the European Commission under its Seventh Framework Programme (http://www.unmanned-ship.org/munin/). MUNIN aims to develop and verify a concept of an autonomous ship, which is defined as a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore side control centre (SCC).

Autonomous operations require programmed voyage planning, navigation and collision avoidance systems, which must be continuously monitored by the SCC. The automated software system will make navigation and engine control decisions based on input from sensors and preprogrammed goals, only asking the SCC for help when needed. The SCC is linked to the ship using whatever communication technologies are available (e.g. GSM, VHF or satellite). The SCC plans and uploads voyage data to the unmanned ship and monitors the ship during the voyage.

The operators are the backbone of the SCC. Within this concept, each operator is required to monitor 6 unmanned vessels via a monitoring and controlling workstation (see figure 1). Each workstation is comprised of 6 dashboards (one per vessel), a customized electronic sea chart and a conning display. The other two blank screens are designed for a radar screen and a weather chart (under development at the time of testing).

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 6 vessels, as well as, categorized and monitor information from each vessel by cycling through each of the 6 dashboards. On the top "layer" of each dashboard there are 9 information panels an operator can explore and monitor specific information about various control processes (see figure1). Each information panel in the dashboard will have a colour flag as the top flag: Green, Yellow or Red. If everything is operating normally (within pre-described operational envelopes) or there is no impending threat, then all 9 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, she 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 1, the category panel "Sailing" indicates a Red Flag, 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, or manual control onboard).

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 supervisor. The task of organizing the operator's workload, for example by reallocating resources in the SCC, is the responsibility of the supervisor. In these trials, it is the supervisor's job to call upon two other SCC actors, if necessary - the SCC captain and/or engineer.

The captain is assumed to be the head of the division and is the person 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 from the SCC.

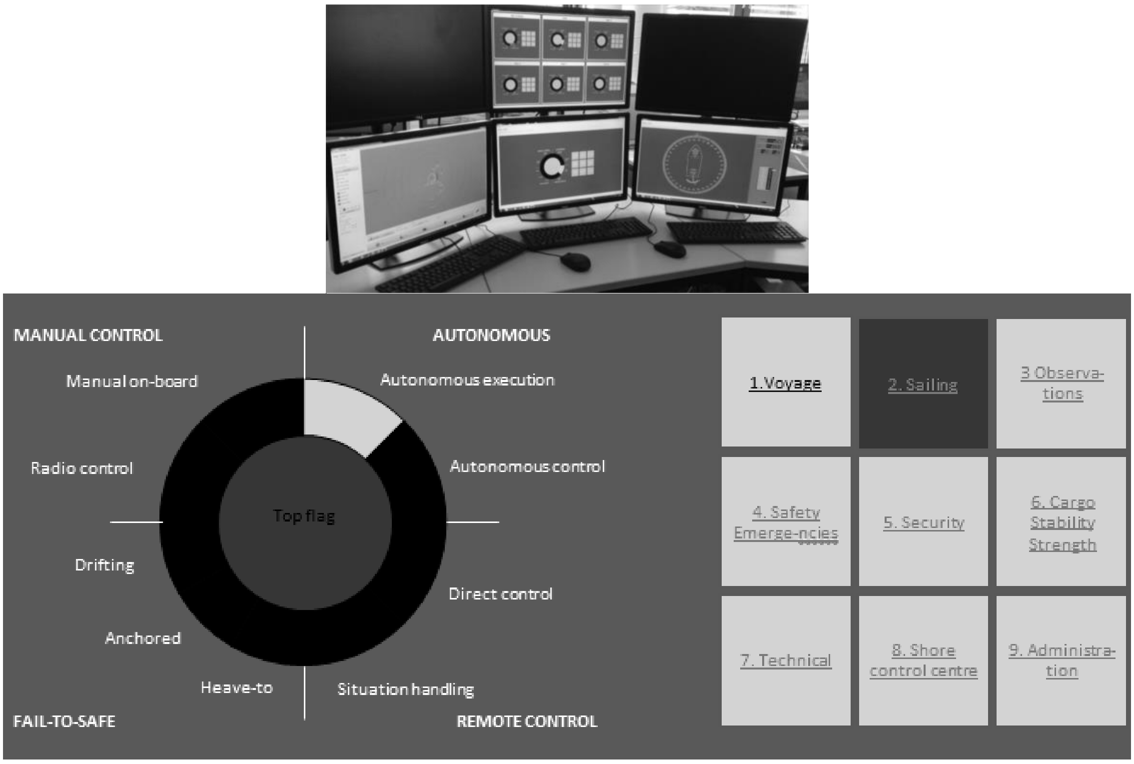

Figure 1. The operator’s workstation (top) and one dashboard to display 9 groups of information from one unmanned ship (bottom).

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.

2. METHODS

Seven volunteer participants, all being either vessel traffic service operators, master mariners or ship engineers underwent six scenarios. Each were assigned “roles” within each scenario, as operator, supervisor, captain or engineer. 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. 3) 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 “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 a 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.

These scenarios were undertaken in a simulated SCC concept (see figure 2).

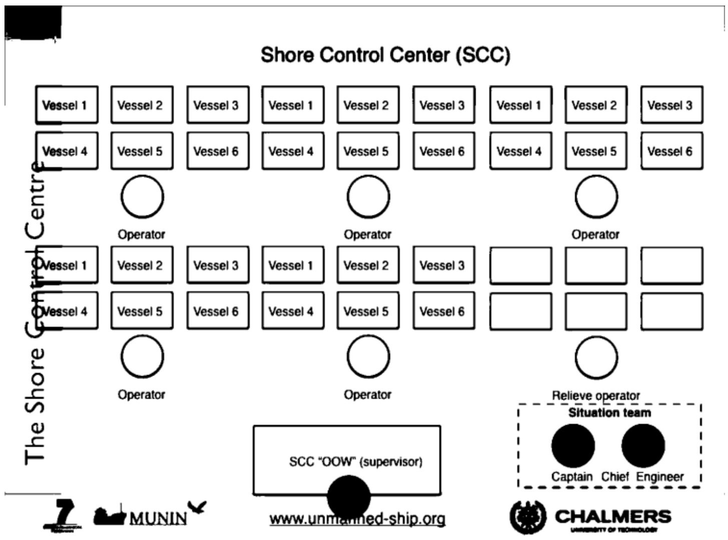

Figure 2. Schematic of Shore Control Centre and personnel.

Following each scenario, each participant was asked to complete a Situation Awareness Rating Technique (SART) questionnaire (Taylor, 1990) and the Quality In Use Scoring Scale (QIUSS) scale (Jones, 2008). These were administered to get a better understanding of how each participant felt they obtained and maintained situation awareness (SA) and how effective the HMI was in achieving these states. A debriefing questionnaire was also administered and included questions relating to HMI design and usability. Its qualitative content was used to interpret the SART and QIUSS responses.

3. RESULTS

SART (Taylor, 1990) is a post-trial subjective rating technique that was originally developed for the assessment of aircraft pilot SA. SART uses the following ten dimensions (order refers to the Question index described on the x-axis of figure 3) to measure operator SA: instability of the situation, complexity of the situation, variability of the situation, arousal, concentration of attention, focusing of attention, spare mental capacity, information quantity, information quality and familiarity of the situation. It requires participants to subjectively rating each dimension on a seven point rating scale (1 = Low, 10 = High) based on their performance of the task under analysis (see figure 3).

The QIUSS comprises four rating scales, namely effectiveness, efficiency, safety (used in a very broad sense) and satisfaction, where a lower score is assigned as a poor attribute to the dimension and a high score reflects a positive rating (Jones, 2008). The rater is asked to rate the dashboard interface after each scenario (see figure 4).

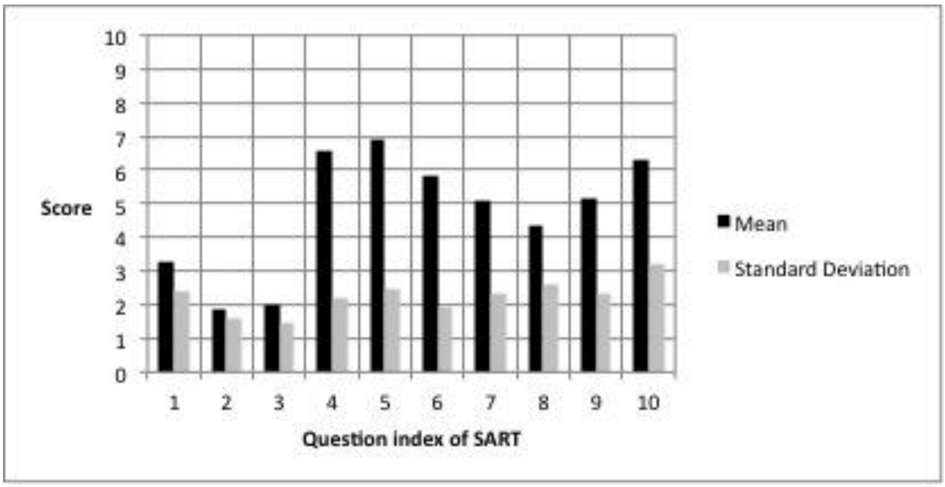

Figure 3. Aggregate results across the six scenarios for all participants and each dimension of SART.

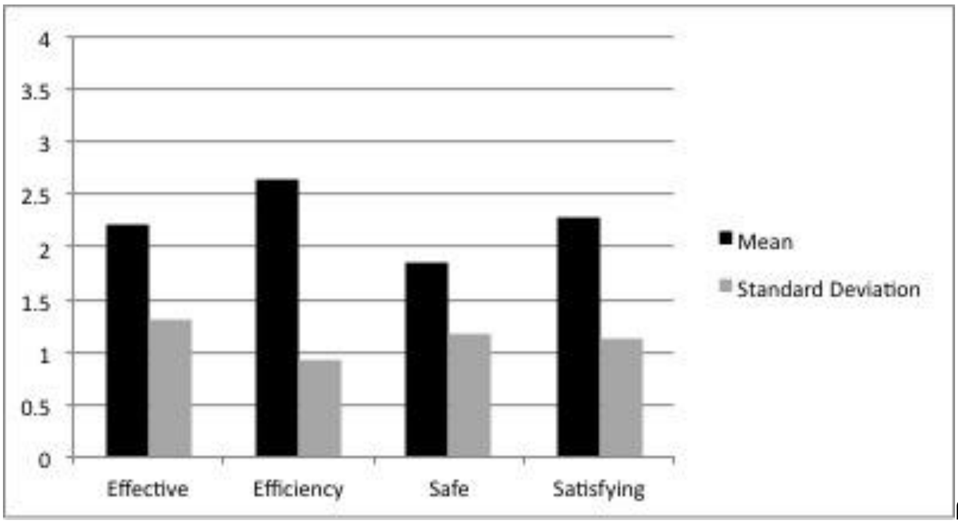

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Figure 4. Aggregate results across the six scenarios for all participants and each dimension of QUISS.

The Debriefing questionnaire provided invaluable information to support the data gained from the SART and QIUSS data and are integrated in the Discussion section.

4. DISCUSSION

Results from the SART and QIUSS data are not surprising. The concept of unmanned, autonomous maritime vehicles is just that – a concept. While the participants were highly skilled mariners, none have experienced a socio-technical system as defined in this SCC context. The debriefing questionnaires were analyzed using a Grounded Theory framework (Corbin and Strauss, 2008). This approach was deemed relevant as this work was question driven and this analysis approach has often been employed in engineering research to explore the relationships between users and innovation. The basic question was “does the SCC concept keep those actors within the prescribed socio-technical system "in-the-loop" - particularly the SCC operator?".

Endsley (1995) 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 (Endsley, 2015).

Bainbridge (1983) 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 (Wilson and Rajan, 1995; Young et al., 2014). 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 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.

While the majority of the research to date has focused on individual SA, the context of this research requires an understanding of Team SA, how it is obtained, maintained, transferred and sustained. Endsley (1995) defines Team SA as "the degree to which every team member possesses the SA needed for his or her job" (p. 39). This means that each team member needs to have the SA required for a specific duty in order for the team to be successful. However, SA may need to flow between team members and may not necessarily be unidirectional. Shared SA is defined as "the degree to which team members have the same SA on shared SA requirements" (Endsley and Jones, 2001, p. 48). The shared SA was supposed to build on the basis of overlapping goals, therefore poor shared SA deteriorates the Team SA while good shared SA doesn't necessarily lead to good Team SA. Team members may not need to share everything they know, but failure to share pertinent SA will likely result in critical errors (Endsley, 2015). Endsley and Jones (2001) identified critical factors impacting upon Team SA and included: A) Sharing of Level 1, 2 and 3 elements; B) devices that could help teams form shared SA including verbal and nonverbal communications, shared displays and shared information; C) Shared mental models; D) Shared SA processes teams employ (through formal training and operational protocols. It is important that the system shall not only support data transfer, such as the ship's position, course and speed displayed on the monitors, but also the process in which data are utilized and used for consensus decision making.

With respect to the SART data (refer to figure 3), there was some disagreement amongst the participants as reflected in the high variability within each measurement. The high variability might reflect the differing demands or pressures placed the different roles (i.e. operator versus engineer) within the different scenarios. There were certainly trends. Participants found the scenarios to be relatively stable, not too complex or variable. In general, participants were positive about the remaining attributes necessary for achievement of SA, such as the quantity and quality of the information and how their attention was focused to the task (task of monitoring information). This suggests the demands of the scenarios were not different from those typically observed (or practiced perhaps in simulation) in day-to-day shipping operations.

Issues that keep the participants from gaining the appropriate levels of SA during the scenarios were reported in a consistent manner in the debriefing questionnaire. While the SCC concept has been described within the overall project requirements, how a team of participants unfamiliar with the concept interacts, such as within this experiment, would be challenging. Unlike a vessel that has clear command and control structures, with a primary decision-maker (i.e. the Captain), a SCC relies on a more fluid and sometime flattened hierarchal structure, where decisions are arrived through consensus. If the operator doesn't feel competent to handle a situation, then a hand-over via the supervisor (refer to figure 2) to a situation handling room may occur. This would likely be a very stressful situation for the operator and under these circumstances, would have to transfer SA quickly to other team members. This is unlike a watch handover on a vessel, but occurs during a period where the operator is likely unsure of the data, the situation is complex or a time pressure has been introduced. These are not circumstances that likely facilitate consistent and complete SA transfer.

The QIUSS data (refer to figure 4) reveals that the participants were neutral (scores hovering around 2) about the automated system and the dashboard interface employed in the SCC. This likely reflects the fact that these are new "technologies" and the participants had no real previous experience with the integrated systems prior to this test. Safety was scored the lowest. The debriefing questionnaire data suggests that the participants lacked a sense of presence or "ship-sense" (Prison et al., 2013), the ability to physically validate (e.g. movement of the vessel, effects of the environment on the maneuverability of the vessel) the virtual data being presented to them through the dashboard. Witmer and Singer (1998) define presence as the subjective experience of being in one place or environment, even when one is physically situated in another. Thus, feedback through visual or auditory data is critical in the future development of a SCC.

Efficiency achieved the highest QIUSS score. This likely reflects the participants' acceptance of a centralized monitoring system. Co-locating all systems under one dashboard, providing a transparent alarm system (with suitable operational envelopes describing what constitutes a green, yellow or red flag) and recommendations (i.e. decision support system) for corrective actions will be important to such distributed systems and the development of their existing mental models. The HMI interface must be designed to allow operators to quickly achieve high levels of SA about the situation of the vessel in question. Logistical and tactical groupings of data must be considered in such an interface and the operator should be clear about what vessel data they are monitoring. Unlike other automated workstations, standardization of future system applications and their implementation is critical.

Notwithstanding a potential "paradigm shift" for the participants, this data collection exercise was enlightening. The concept of a SCC still must evolve. Technical solutions will be forthcoming and limitations of existing technologies should not be considered a barrier in evolving this concept. Pedagogical issues are also critical to the success of such a concept. The SCC is not an evolution of Vessel Traffic Services. The SCC may be more aligned to the aviation industry: *Would an aircraft pilot make a suitable air traffic controller? Why is an air traffic controller educated differently from a pilot? Are the skill sets of a successful air traffic controller the same as those of a pilot*? There remains a pedagogical gap that will have to be addressed.

Automation should never be considered a fail-proof option and has been known to result in dangerous consequences when the human operator is suddenly made-in-charge of an emerging situation previously controlled through automated processes. The operator is suddenly shifted from a passive monitor (out-of-the-loop) to an active decision maker (in-the-loop). Furthermore, in team situations, obtaining, transferring and regaining SA can be difficult. Should team members not possess the needed SA or not share the same mental model of the situation, errors will likely occur.

5. CONCLUSIONS

Automation, as a technical solution, is not the answer to evolve the concept of unmanned, autonomous vessels. Humans must be retained within a system that is primarily controlled by intelligent computers in order to handle unexpected events not anticipated by the designers of the automated system (Reason, 1990). Not all failures or latent system errors can be predicted. The concept of a SCC that controls unmanned, autonomous deep-sea vessels is a concept not far from reality.

ACKNOWLEDGMENTS

The authors would like to acknowledge the European Commission - Seventh Framework Programme (http://www.unmanned-ship.org/munin/) for funding this project and the Stiftelsen Sveriges Sjomanshus (Swedish Mercantile Marine Foundation) for providing funding to authors.

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