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Time Budget for Merchant Ship Control Takeover - Preliminary Results

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ABSTRACT: The increasing automation of shipping requires a proper understanding of the behavior of those in command of ships to be able to correctly mimic and interpret their actions. This will be especially important during the widespread introduction of autonomous merchant vessels, whose decision-making algorithms will need to be correctly prepared to assess situational awareness and will allow for timely control takeover in a variety of circumstances, including mixed navigation conditions. Therefore, this research aims to investigate the safety-critical situations when the assistance of a captain is required by the watch officer. There can be various situations when such a person is called and asked to proceed to Bridge and exercise his/her experience to help the younger and less skilled colleague in a potentially dangerous situation. In the study, we asked experienced Masters Mariners about their perception of such a situation. We investigated whether it depends on their sea-time experience and other factors (e.g. traffic density, weather conditions, fatigue) in a particular situation on board the vessel. The results of this study may prove valuable in determining the time required for obtaining a situation awareness during control takeover in different situations. The collected results may also prove useful in designing and developing navigation simulator exercise scenarios in the context of assessing situational awareness or providing control-taking guidelines for Maritime Autonomous Surface Ships (MASS).

1 INTRODUCTION

With transportation modes progressing towards advanced human-machine teaming and eventually - autonomy, the topic of handing over control between agents remains critical. Among the benefits of autonomous vehicles, one can mention improved performance in relatively low-complexity environments, such as highways, railroads, or open sea navigation [1]. Therein, it is postulated that an advanced array of environmental sensors and data analysis algorithms can provide a vehicle with sufficient situation awareness (SA). However, unexpected events can still occur there of such a nature that a vehicle may not necessarily be capable of handling them on its own and may eventually require driver's assistance [2,3]. The vehicle itself can also leave its Operational Design Domain (ODD) at some point and by that enter an environment in which it cannot safely drive itself [4][5]. So far, there are hardly any systems that can operate completely independently from their operators - even high-end deep-space probes do require some intervention from time to time [6]. It is therefore a matter of time until an autonomous vehicle requires the driver's assistance in handling (un)expected control handover [7]. That raises two basic questions: (1) what circumstances do push the vehicle out of its ODD? and (2) how much time is needed for an operator to safely assume control? Using expert knowledge, the herein study aims to answer these questions for a specific type of vehicle, which is ocean-going merchant vessel.

The issue of determining the time budget [8] for a takeover procedure is critical for ensuring the safety of automated vehicles. Ever since a highway hypnosis hypothesis was formulated [9], it has been widely accepted that humans are poor supervisors of highly automated systems [10]. Their minds drift away from the supervisory task that does not require constant interaction with a controlled system. With situational awareness degrading in time, it cannot be assumed that humans can be brought back to the loop in an instant [11]. The question therefore arises: if the time required for a safe takeover is not zero, then what is it? Some studies suggest values of around or more than 20 seconds [11,12], but they assume a physical presence of a taking-over actor in the control room. This may not always be the case, for instance when considering a Maritime Autonomous Surface Ship (MASS) of such a design that an autonomous control system requests a takeover from onboard personnel rather than from a Remote Operator (RO). In this concept, a reduced crew is kept on board with no obligation to monitor the ship constantly but is expected to intervene upon being prompted. Noteworthy, this setup is similar to that of contemporary Unattended Machinery Spaces where duty engineers can rest in their quarters while on watch.

In our study, we attempted to answer the above questions indirectly, by asking subjects about their previous experience in taking conn from a somewhat autonomous (from their perspective) system - a ship.

2 MATERIALS AND METHODS

For the herein study, we deem a regular merchant ship as autonomous, as the primary target of our research were the heads of a deck department, namely Master Mariners, who are also referred to hereinafter as seniors. We have asked them about their experiences of being called to the navigational bridge by a more junior officer. Such a call can be triggered by a variety of events as listed in relevant operational procedures, ranging from safety-critical ones (receiving distress signals, close-quarters situation developing) to commercial ones (for instance, new orders received) [13]. From the seniors' perspective, the system (a ship) has been operated autonomously: without interaction with them, until such interaction was required. Once it happens, they are required to gain necessary information pertaining to the reason for being prompted without prior knowledge of the rationale behind the call and a degree of urgency and do so as quickly as possible. They must then assume the control, and steer the system in a direction required by circumstances. Needless to say, there is a significant pressure on them especially in the initial part of the process when they need to evaluate not only how time-critical it is to decide on the further course of action but also to make sure that the decisions made are actually correct ones. There can also be a case when juniors call them too late to take any decisive action, just as may happen when self-driving cars alert the driver in insufficient advance.

To collect seniors' experiences about the master to the bridge situations, we set up an online questionnaire. To ensure the relevance and accuracy of the survey, it was developed in collaboration with marine officers, including experienced Master Mariners. These experts were consulted to identify key situations that typically require a handover of control on board ocean-going merchant ships. Their input helped in designing questions that accurately reflected real-world scenarios, such as emergency calls to the bridge, technical failures, adverse weather conditions, and collision avoidance.

An invite has been sent to various shipping companies, seafarers' associations, etc. to promote it. Additionally, a request to invite more respondents was included which makes a response rate impossible to calculate. Eventually, 47 individuals (all were males and held the Master Mariners licenses) filled out the questionnaire. Their demographic breakdown is presented in Figure 1.

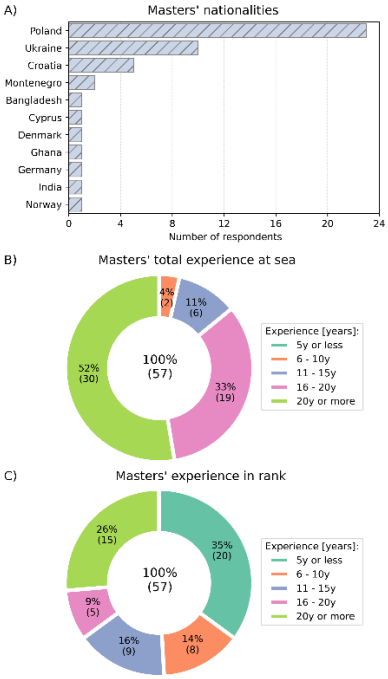

Figure 1. Demographic data of the respondents

3 RESULTS

3.1 *Overview*

Of 47 Master Mariners elicited, 38 declared having been called to the bridge in an emergency on an average of about 11 times during their career span (ranging from 1 to 30). Then, the respondents were requested to list the most frequent reasons for which they have been called to the bridge. The breakdown of the received answers is depicted in Figure 2.

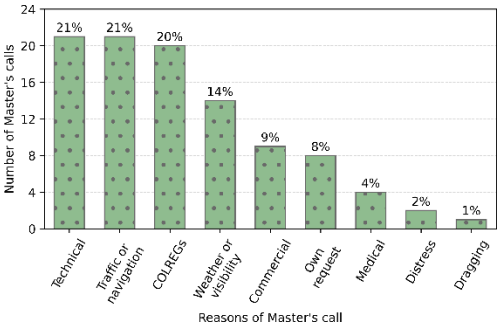

Figure 2. The most frequent reasons for which senior officers have been called to the navigational bridge

In the next step, participants were asked to estimate the time needed for them to reach the bridge and gain situation awareness to the point, in which they would be ready to make necessary decisions. On average, they declared some 2.9 minutes in emergencies and 6.1 minutes in routine circumstances. A histogram of their answers is given in Figure 3. Noteworthy, the time declared by subjects as required to reach the navigational bridge and gain the SA showed a near-zero (-0.007) Pearson correlation coefficient with their experience: both in rank and in total. This indicates that with respect to time budget management, experienced captains do not seem any better than inexperienced ones, at least declaratively.

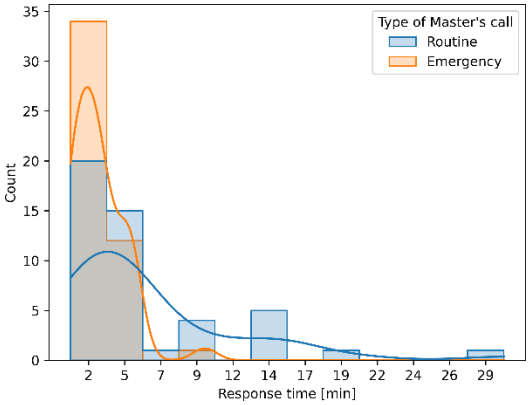

Figure 3. Time needed to reach the navigational bridge and gain situation awareness

In the further part of the study, the respondents were asked to recall their most recent emergency call to bridge and the most stressful one. These questions were not required in the survey, and thus have not been answered by some of the respondents, so the sample sizes can vary.

3.2 *Most recent experiences*

Over 90% of the most recent calls to Master have been related to either collision avoidance, technical failures, or weather conditions. The respondents declared that it took them some 3.2 minutes (on average) to build the situation awareness and take the conn from the moment they were called. Their time budget amounted to an average of 10.3 minutes. They also stated that the handover by an OOW was effective (32 responses) or partly effective (5 responses). However, in 9 cases they mentioned that the bridge alarm system did not help gain their situation awareness. This could indicate that, for some reason, the subjects perceived human-to-human information exchange as more effective than the machine-to-human one.

However, the most recent experience does not give a relevant picture of situations in which it would be critical to execute a smooth and efficient handover. These would rather consist of situations that have been found most stressful by the subjects.

3.3 *Most stressful experiences*

From the safety perspective, it can be raised that the more stressful the situation is, the more disastrous can be its potential consequences. Therefore, a level of stress felt by operators can serve as an indicator of how dangerous the circumstances might have become if not for mitigating actions taken. With this in mind, it is necessary to take a closer look at situations in which the efficient and safe hand-over was critical for the safety of the vessel involved. As can be seen in Figure 4, the breakdown of these most stressful situations is to some extent similar to the overall breakdown of situations, in which master's assistance was required (see Figure 2). However, a few interesting points can be noted:

- Traffic and navigation-related calls were in general less stressful (challenging) even though they were quite frequent.
- Situations related to collision avoidance were the most frequently labeled as most stressful while their frequency was similar to that of Technical and Traffic/navigation. It is of note that captains (respondents in this study) are by default the most experienced nautical officers on board their vessels and they were still the most stressed in collision avoidance situations, ones that they have likely personally resolved countless times in their careers. This, in turn, may indicate that they have been called by OOWs too late into ships encounters. It can also be noted that situations related to collision avoidance are caused by direct actions of some humans - crewmembers of both Own Ship and Target Ship(s). These are unlike other factors leading to frequently stressful calls to Master, such as Technical breakdowns (which can be random or can result from factors with which nautical officers are usually less familiar) and Weather conditions, which are natural phenomena outside of human control.
- Respondents indicated that Fire on board was among the most stressful situations in which they were called to the bridge. This answer was not predefined in the survey and even the respondents who provided them here did not mention Fire in previous, open-answer questions. By this, the respondents did not associate fire with situations they would be normally expected to handle and focused on those related to their more routine duties (navigation, collision avoidance, communication) when asked a routine question. It was not until they were asked specifically about the most stressful (challenging) event they have found themselves in that they mentioned a rare but extremely dangerous event.

The respondents declared that it took them some 3.1 minutes to arrive at the bridge and build the situation awareness from the moment they were called to assist the OOW, which is similar to the times declared previously. However, they also declared a time budget of 8.1 minutes - some 21% less than in the most recent situations (10.3 minutes). The latter are not necessarily highly challenging (some of them are, but others are not). The fact that it took Masters a similar time to respond to the call in the most stressful and 'average' situations indicates that they react to the call by an OOW in a similar way. Presumably, it would take too much time for a caller to explain all circumstances to the captain and specify the level of urgency. Masters would rather respond to the call as quickly as possible and determine the urgency only upon arriving at the conning station. Time budget can be named as a proxy of such urgency - the less time is available to avert a hazard, the more urgent is master's intervention. 10.3 minutes on average, 8.1 minutes when the situation drifts into hazard.

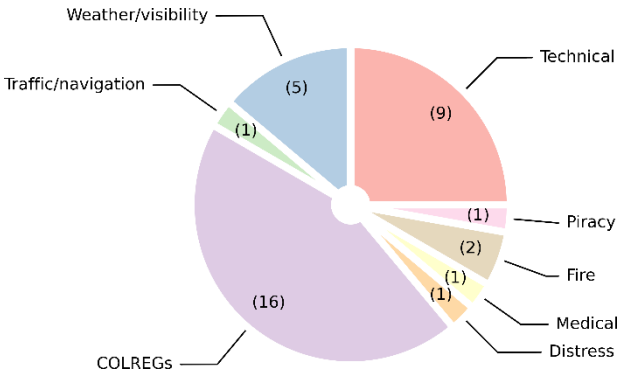

Figure 4. Most stressful reasons for calling Captains according to the respondents

The control takeover process was evaluated more skeptically than in an average situation. Handover by an OOW was partly effective in 9 of 37 cases and ineffective in only one case. Messages and alarms produced by bridge automation were partly effective in eight cases and ineffective in 11 of 37 cases (30%). This indicates that particularly in stressful and demanding situations, messages automatically generated by devices installed on the navigational bridge are of limited help. As the purpose of these messages is to improve operators' situation awareness by attracting their attention to the potentially dangerous factors, the fact that they are not as useful as should be may indicate a need to re-think their design. This is particularly important for automation-to-human handovers in non-routine situations. Herein, the person taking the sole conn of the MASS would have to rely only on information fed by the automation, at least in the initial phase of take-over. They would not have the privilege of human-to-human hand-over, which allows for an exchange of non-standard information. Note that OOW handing over to master was evaluated as effective in 27 of 37 most stressful situations while the bridge alarming system was only effective in 18 of them.

4 DISCUSSION

In the below subsections, the outcomes of the performed study are discussed along with its limitations.

4.1 *Findings*

The performed study helped investigate situations in which experienced Master Mariners have been called to assist their less experienced colleagues in potentially hazardous or otherwise non-standard situations. It also made it possible to assess the time required to gain situational awareness as well as to take control of the ship. The entire master to the bridge call along with the study results discussed in the subsequent paragraphs are graphically summarized in Figure 5.

Firstly, a breakdown of types of such situations and their levels of urgency have been identified. Most of the situations in which masters are called to the bridge are related to technical malfunctions, deteriorating weather, and traffic conditions including a direct threat of collision. Among the less frequent answers that may be relevant for MASS are: receiving a distress signal and dragging anchor. From a perspective of MASS design, it must be noted that the list is not exhaustive and that the assistance of a human operator (not necessarily a certified Master Mariner) may be necessary in even less standard and unexpected circumstances. To this end, the case of Fire as outlined above serves as a good example. Herein, respondents did not list Fire as a reason for being called to bridge, until asked about the most stressful situation in which it so happened to them. This indicates a need for a careful design of MASS control systems, taking into considerations the knowledge of properly and thoroughly elicited, experienced seafarers. After all, how many non-standard, infrequent yet safety- or security-critical situations can be out there at high seas? Not in the handbooks, procedures or accident reports, but living memories of professionals.

Secondly, the declared times in which Masters gain situation awareness and react to the circumstances met have been studied. It has been found that masters reach the bridge and obtain a situation awareness in some 3 or so minutes on average. This does not appear to depend on the urgency of the situation in which their assistance was found necessary or required by operational procedures.

It is of note that maximum declared times, being the most critical from the safety perspective, were in some cases (see Figure 3) several times larger than obtained mean values.

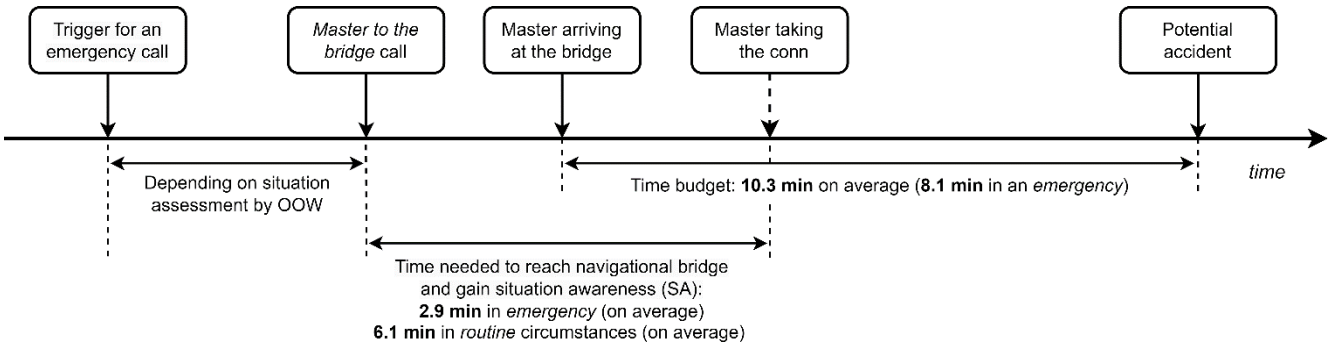

Figure 5. Graphical summary of the 'master to the bridge' procedure during the navigation process and its implications for situational awareness and control takeover, inspired by [8]

The outlying ones reached even up to 30 minutes for routine and 10 minutes for emergency master to the bridge call. Interestingly, quite a few of the captains (9 of 47, i.e. almost 20% of the sample) reported they were able to reach the bridge and gain SA in 5 minutes in case of emergency. A total of 8 of them declared that their last offshore assignment had been done on board of container vessel, which is a rather fast ship type compared to other merchant ones. Thus, conservatively assuming 18 knots as a representative speed, it means that between calling the master and his response, the ship advances some 1.5 NM and can eventually get significantly closer to the potential threat (e.g. during a close-quarters situation). Consideration of these times of control takeover on manned ships seems to be of utmost importance to ensure proper response of MASS during mixed traffic conditions when an autonomous ship will meet and try to mimic the behavior of a manned one or at least correctly interpret the development of ship encounter.

However, it must be noted that the declared time required to reach the conning station and gain the situation awareness does not account for the fact that masters need to physically move from wherever they are to the bridge. This may be different from the MASS Remote Operations Centre setup where operators would likely be seated in a direct vicinity of their respective control consoles.

4.2 *Limitations*

Among the limitations of the current study, potentially affecting the credibility of its results, the following issues can be listed:

- the questionnaire was filled out by 47 Master Mariners. Only 37 of them responded to all the questions. Given the fact that there are some 50,000+ ships registered globally [14] and likely twice as many certified Master Mariners, our sample can hardly be called representative. However, the answers provided by even such a small sample do indicate some factors that may be found relevant for the development of prospective MASS and can be used to bring attention to these factors;
- the performed study was based on respondents' declarations rather than solid experimental data. Respondents were requested to retrieve certain facts from memory, which can be misleading.

5 CONCLUSIONS

This study sheds light on the critical aspects of control takeover in maritime settings, particularly for ocean-going merchant ships. The findings emphasize the importance of timely and effective human intervention when unexpected situations arise. Our findings highlight the significant variability in response times and the nature of situations that necessitate the intervention of experienced personnel, such as Master Mariners, when control is handed over from junior officers.

It was found that the most common triggers for emergency calls to the bridge were collision threats (44%), technical malfunctions (25%), heavy traffic (21%), and adverse weather conditions (14%). The survey results indicate that captains generally require about 3 minutes to respond to an emergency call and achieve sufficient situational awareness to take control of the vessel. This response time appeared relatively consistent regardless of the urgency or stress associated with the event, suggesting a standardized approach by masters to emergencies.

However, the study also reveals a significant gap in the effectiveness of automated alert systems compared to human-to-human communication during handovers. In high-stress situations, automated systems were often found to be less effective in conveying critical information, suggesting that current designs may not adequately support decision-making under pressure. This limitation points to a need for enhancing the design of these systems, especially as the maritime industry moves towards greater automation and the development of Maritime Autonomous Surface Ships (MASS).

The insights gained from this research highlight the ongoing necessity for human oversight in automated systems and the need for further refinement of control handover processes. Future advancements should focus on improving the reliability and intuitiveness of automated alerts and ensuring that human operators, whether on board or remote, can seamlessly take over control when needed.

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