15 HMI Measures for Improved Sensemaking in Dynamic Positioning Operations

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CONTENTS

INTRODUCTION

There is currently a considerable drive toward increasing levels of automation across all complex, safety-critical industries. In the transportation domain, we see numerous autonomous concepts of operation emerging, such as self-driving cars, autonomous ships, remotely operated drones and underwater vehicles – all concepts where the role of the operator is shifting from active, hands-on operation toward a more managerially oriented role focused on administering and supervising a suite of automated systems. In commercial aviation, this has been especially prevalent and has contributed to an impressive safety trend over the past few decades, but we have also seen new types of accidents resulting from a breakdown in the collaboration between the pilots and various automatic control systems. A recent example is the two Boeing 737 MAX 8 crashes where a newly installed automatic anti-stall system unexpectedly and repeatedly pushed the nose of the plane down. To make matters worse, it was designed in a way that made manual intervention difficult even when the pilots finally understood what was happening (National Transportation Safety Board, 2019).

In this chapter, we look at this challenge from the perspective of a modern ship bridge, and more specifically the operation of dynamic positioning systems (DP systems). This technology is utilized for automatic station keeping and is becoming ubiquitous in the maritime domain in a wide variety of operations such as drilling, cargo loading, diving operations and pipe-laying. As such, various industries increasingly depend on the safe operation of these systems, and the considerable number of incidents and accidents that have occurred in recent years are causing concern.

The work presented in the following is the result of a study performed within the sensemaking in safety-critical situations (SMACS) research project (SINTEF, 2018) supported by the Norwegian Research Council and industry partners Human Factors in Control (HFC) forum and Kongsberg Maritime, focusing on human–machine interfaces (HMIs). Sensemaking refers to the ability of operators to perceive and understand situations and act accordingly in complex environments (Kilskar et al., 2018; Weick, 1988). It is closely related to "Situation Awareness" (SA) as described by Endsley and Jones (2012). The purpose of this study has been to identify the factors that challenge the sensemaking of DP operators (DPOs) and to propose new design principles for effective human–automation interaction that may improve safety.

This has been a mixed-method feasibility study with a strong focus on end-user involvement and learning from related safety-critical domains that Institute for Energy Technology (IFE) has worked with. The study first identified key challenges through semi-structured interviews with instructors and experienced DPOs, observations during simulator-based DP training, discussions with Equinor "Captains forum" and analysis of incident and accident reports, summarized in Hurlen, Skjerve & Bye (2019). Design opportunities was then explored and exemplified through mock-ups (Hurlen & Bye, 2020) and finally evaluated with end-users, summarized at the end of this chapter.

DYNAMIC POSITIONING (DP)

To understand the context, let us first look at DP operations, how the system works and how it is used. The system itself works by automatically controlling thrusters and rudders to keep a predetermined position, using input from a variety of reference systems – position reference systems (such as radar, GPS, hydroacoustic and laser systems) and sensors measuring external forces acting on the vessel (wind and current) – to compute and execute the force necessary for station-keeping. DP systems are classed 1–3 according to their level of technical redundancy. Class 3 is generally required for safety-critical operations and involves the capability of no single fault in an active system causing the system to fail and is also being able to withstand fire or flood in any one compartment without the system failing (see IMO publication 645).

For many types of operations, this is increasingly becoming a preferred way of maintaining position as an alternative to anchoring. Depending on the operation, DP systems are used more or less prevalently. A cargo vessel may use it for only a few

FIGURE 15.1 Modern ship bridge environment with dynamic positioning (DP) systems. (Training simulator, photo by Kongsberg Maritime.)

hours during offloading while a drilling or construction vessel may spend most of its time on DP. While the vessel is on DP, a dedicated DPO on the ship bridge is responsible for supervising and controlling the system, which includes ongoing risk assessment, setting and adjusting position setpoints according to changing operational needs and weather conditions, managing reference systems and collaborate with the rest of the ship crew. The DP system can operate in a variety of modes, including full auto position and a variety of combinational modes where the DPO assists the automation in specific ways. For example, the system can be set to automatically maintain the heading of the vessel into the prevailing weather (weathervane mode), follow a remotely operated underwater vehicle (ROV) or maintain position less strictly in order to save fuel (eco mode).

Figure 15.1 shows a modern ship bridge with DP interfaces. As we can see, this is a highly computerized environment. Although a typical bridge still features a lot of analogue equipment, digitalization are a major trend. Computer graphics is increasingly being utilized to convey information about the vessel, its control systems and its surroundings. As shown in Figure 15.1, DP system interfaces typically consist of a panel with physical buttons and joysticks for key mode selections and system configurations, and a number of configurable screens that show system status, alarms, trends and other relevant information. Advanced diagnostic features include a “capability plot” that graphically draws a boundary around the vessel representation, indicating available directional force in case of worst case single-failure event and consequence analysis warnings.

CURRENT CHALLENGES

Accidents and near-misses reports indicate that the sensemaking of DPOs is not always successful. As in most other complex, fast-paced, safety-critical environments, DPOs often face significant challenges when trying to get a proper overview and make sense of the situations they find themselves in. As control systems are increasingly being digitalized, the available amount of information and control opportunities escalate, and the way they are designed most often leaves the human operator with the task of navigating and counteracting their various strengths and weaknesses, capabilities

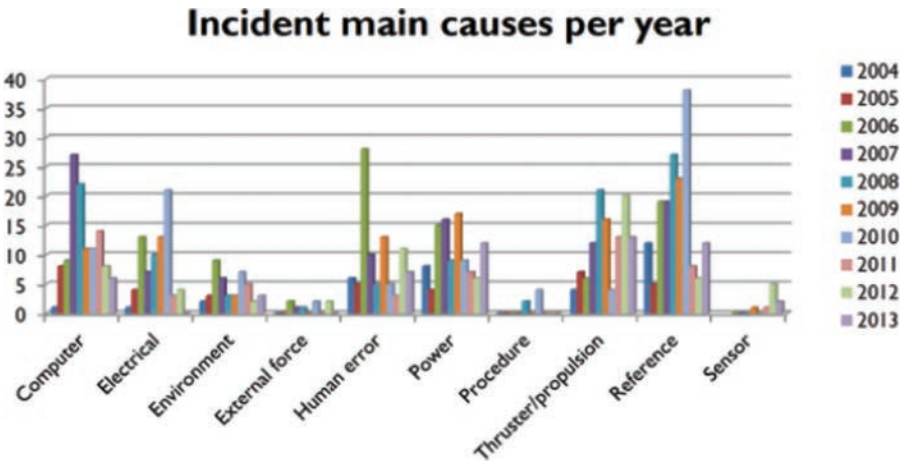

FIGURE 15.2 Dynamic positioning (DP)-related incidents reported to IMCA, 2004–2013.

and limitations. From a purely technical perspective, much of current ship navigation and control system management is fully automated, but the operators are ultimately responsible for maintaining safety – the final barrier in the chain of defense. In the years 2004–2013, up to 27 DP-related yearly incidents reported to IMCA were labeled "human error" as their root cause, see Figure 15.2 (IMCA, 2016).

Our analysis suggests that these human errors most often can be traced back to poor system design – to putting human operators in a position where they are unreasonably vulnerable to failure. In this study, we therefore adopt a user-centered design perspective, assuming that when technology is properly designed and aligned with human capabilities and limitations, operators are able to work safely and effectively in collaboration with it. Based on interviews, observations and incident report analysis, we have identified six main sensemaking-related challenges that are currently facing DPOs (Hurlen, Skjerve & Bye, 2019): (1) alarms, (2) mode surprises, (3) critical information hidden from view, (4) "Private" HMIs limits shared SA, (5) deskilling and (6) out-of-the loop.

Alarms seem to be an issue that is particularly challenging for DPOs, either because there are too many alarms being announced in a short period of time, or that alarms or warnings that should have been announced were not, or that they were not properly recognized or clearly understood. Another category that we found particularly interesting because of its familiarity with a well-known issue in related safety-critical domains is the "critical information hidden from view" challenge. DPOs require an extensive amount of status information from the DP system in order to maintain their SA. Because of space limitations on the bridge, a typical DP setup consists of one to three screens. Since not all relevant information can be presented simultaneously on these screens, system providers allow users to organize the content and layout quite freely – so-called user-configurable screens. And since safety-critical situations often happen rapidly and unexpectedly, the information that is presented on user-configurable screens at any one moment may or may not be the one the DPOs need to make a correct assessment of the situation and to best evaluate the effect of any countermeasures that are being made. It could be that the current user has actively organized the screens to best fit the planned situation (and thus not necessarily for the developing off-normal situation) or that the previous user has arranged the screens to fit his or hers personal preferences which may not entirely serve the current user and situation. But since the screens can be re-configured at any time by the users, why is this a problem? Why cannot the DPOs simply reorganize their screens to best fit changing circumstances?

When the nuclear industry began digitalizing powerplant control rooms, similar issues were raised. In the old, analogue control rooms, every process function and every component had its own dedicated, analogue control mechanism, located at a fixed position in the room (so-called "spatially dedicated" interfaces). The new screen-based control systems on the other hand were highly flexible (user configurable), and the users could bring up any component or any piece of information on any screen. By system developers this was considered an advantage: more compact control environments could be made, more powerful information graphics could be designed, control functions could be organized according to changing circumstances and needs, interface maintenance could be performed with less effort, etc. All good stuff, but could all this flexibility also lead to confusion and reduced process overview? Operators were concerned. A study was initiated by the US Nuclear Regulatory Commission (NRC, 2002) to investigate the effects of interface management tasks on operator performance. It concluded:

> When HSIs [Human System Interfaces] are spatially dedicated, operators can use automatic information processing capabilities, such as scanning and pattern recognition, to rapidly assess plant situations. The flexibility of computer-based HSIs and their general lack of spatial dedication causes interface management tasks to be more dependent on controlled information processing. The flexibility also makes it easier for operators to mistake one display for another, and may cause them to improperly assess a situation or operate the wrong piece of equipment.
>
> *(O'Hara et al., 2002, p.7)*

The study also noted that operators were less likely to perform interface management tasks during stressful situations, relying instead on information that were immediately available to them. That operators coming from an analogue control room to a digitalized one often find it difficult to get a proper situation overview is supported by the research performed at IFE Halden for the nuclear industry (e.g. Kaarstad & Strand, 2010; Kaarstad et al., 2008). This helps explain why "information hidden from view" is indeed a challenge for DPOs. During our interviews, we noted several statements related to this. One said: "He who sat there [at the DP desk] before might think he is the world champion and has changed everything around. Very many might then miss important information, especially signals that point towards things that can go wrong." Another stated that "if the information is not already on the screen it will not be used".

This point toward a potentially effective design measure for digital control environments that is increasingly becoming industry standard in the nuclear and petroleum industries: The "spatially dedicated" overview display.

OVERVIEW DISPLAYS FOR IMPROVED SITUATION AWARENESS

Based on studies like the ones mentioned in the previous section, IFE has worked extensively with the petroleum and nuclear industry to explore concepts and solutions that would take advantage of new possibilities as well as mitigate some of the challenges associated with the emerging computerized interfaces, see Braseth et al. (2009) for a summary. Among the most influential concepts that has been developed is the shared overview display, sometimes also referred to as a Large Overview Display or Group-View Display. The purpose of an overview display is to provide individuals and teams in the control room with an at-a-glance overview of the most important safety-critical process parameters at a fixed location in the room, enabling them to quickly assess the current situation, notice deviations early and to prioritize effectively between multiple events without having to "dig" for information in the control system (navigate). After a series of lab studies, industry development projects and experience reviews, a growing body of knowledge attests to their effectiveness (see Laarni et al., 2009; Hurlen et al., 2015; Kortschot et al., 2018; Kaarstad & Strand, 2011; Roth et al., 2001; Veland et al., 2010). When combined with fully flexible interfaces, a well-designed overview display enables the operators *simultaneously* to adapt the HMI to changing circumstances *and* to quickly assess the "big picture" without missing important information. Figure 15.3 shows a typical petroleum control room with a shared overview display.

An emphasis in IFEs overview display design work has been given to designing effective information graphics – visuals that enable operators to directly *see* the process status rather than having to read/reflect on e.g. textual alarm descriptions, providing faster decision support that is especially valuable in stressful situations. As an example, IFE has patented the "mini trend" graphic (Braseth, 2015; adapted for nuclear domain in Svengren et al., 2014, p. 153) illustrated in Figure 15.4. This graphic combines the trend line, relevant alarm limits and the current numerical value in a timeframe suited for drawing operators' attention early to developing deviations.

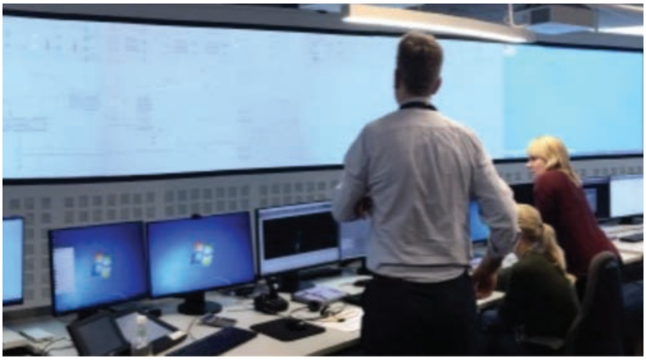

FIGURE 15.3 Petroleum control room combining a shared overview display (top) and flexible screens (bottom).

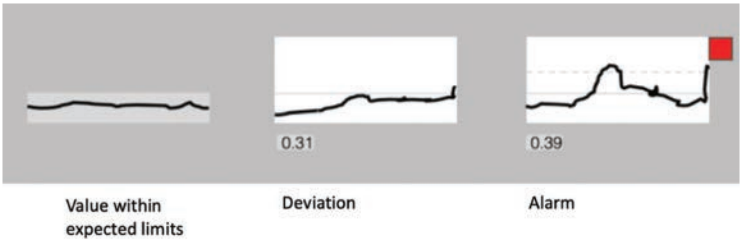

FIGURE 15.4 Mini-trend information graphic.

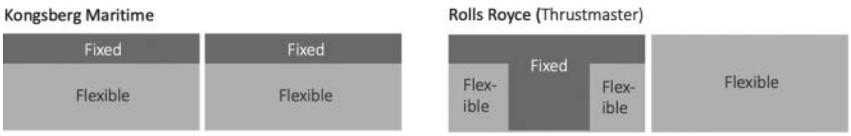

FIGURE 15.5 Dynamic positioning (DP) screen layout: two current industry practice examples that combine fixed and flexible content.

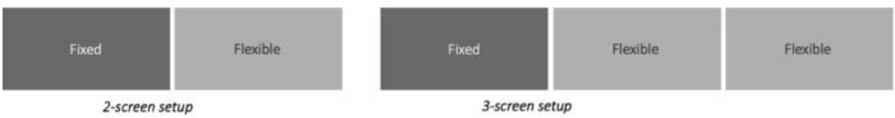

FIGURE 15.6 Alternative layout dedicating more screen space to fixed content.

TOWARD AN OVERVIEW DISPLAY DESIGN FOR DP OPERATION

Could a fixed (spatially dedicated) overview display also help DPOs strengthen their SA? Current industry DP systems also combine flexible and fixed elements in their layouts. Figure 15.5 shows common DP system HMIs, illustrated in a two-screen setup.

Based on the "critical information hidden from view" challenge that has been identified, we wanted to investigate whether SA could be improved by extending the screen area dedicated to fixed information. Figure 15.6 shows an alternative layout design.

To assess the feasibility and effectiveness of this idea, three main questions need to be answered: (1) Is it possible to define a unique set of safety-critical information elements that provides DPOs with "the big picture" relevant in all (or at least the most safety-critical) situations? (2) Is it possible to present this information on a display that is compact enough to fit within the DPOs field of view on typical bridge environments? (3) Could such a design improve DPO performance (sensemaking and SA) in safety-critical situations?

In Hurlen & Bye (2020), we explored a possible design in order to exemplify how an effective solution might be accomplished and made mock-ups suited for

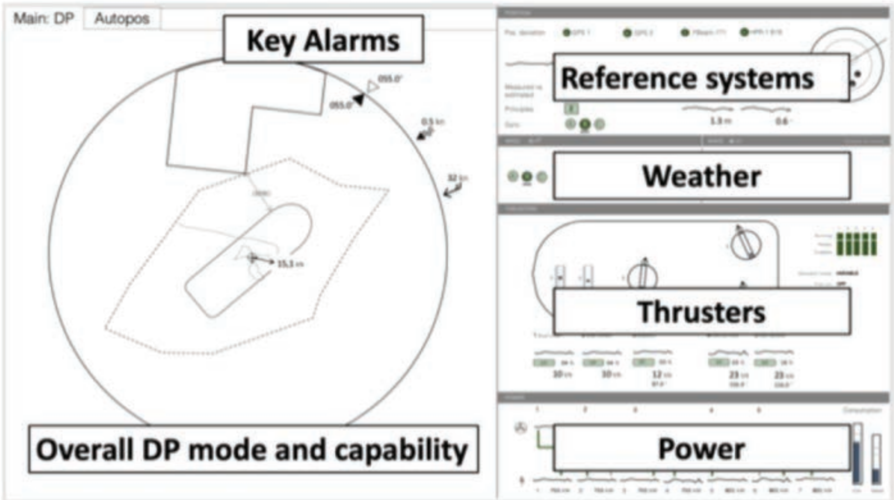

FIGURE 15.7 Possible overview display design layout and main content. (From Hurlen & Bye 2020.)

evaluation with end-users based on the information needs that were identified so far. The main content includes absolute and relative position of the vessel, current position setpoint, status of active reference systems, weather conditions, thrusters, power supply systems and alarms/warnings. A possible layout for a DP overview display is shown in Figure 15.7.

Based on the lessons learned from overview display design in the nuclear and petroleum domain, mock-ups were made to illustrate how the display could behave during different circumstances. Key design objectives in this work were to support “at-a-glance” use, creating information graphics that might give DPOs early warnings and thus extended time to handle disturbances before they reach a critical stage, and highlighting automation mode-related information for which our interviews and incident analysis also identified some challenges.

Please remember that this design is meant to be combined with flexible elements needed for necessary HMI adaption to changing circumstances. The design mock-ups are shown in Figures 15.8–15.10.

RESULTS FROM EVALUATION WITH END-USERS

To assess the feasibility of the overview display design idea, the mock-ups described above were presented and discussed with four experienced DPOs. They each had 3–9 years of operative DPO experience from a variety of vessels and operations, including cargo, construction and production vessels (rigs). Two were also experienced DP instructors. The DPOs were interviewed individually on video. The interviews were performed in a semi-structured manner and organized around the four main topics presented below. A possible weakness with this method is that interview

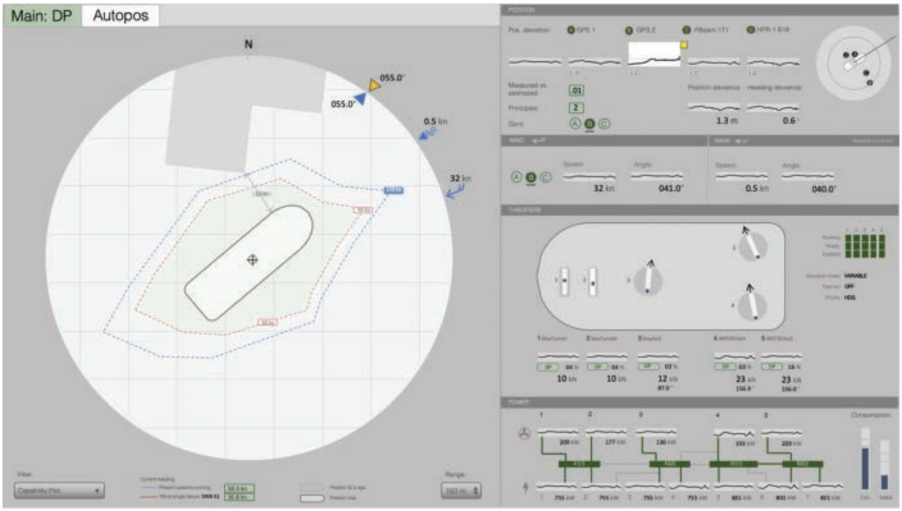

FIGURE 15.8 Possible overview display design – normal operation with minor disturbance. (From Hurlen & Bye 2020.)

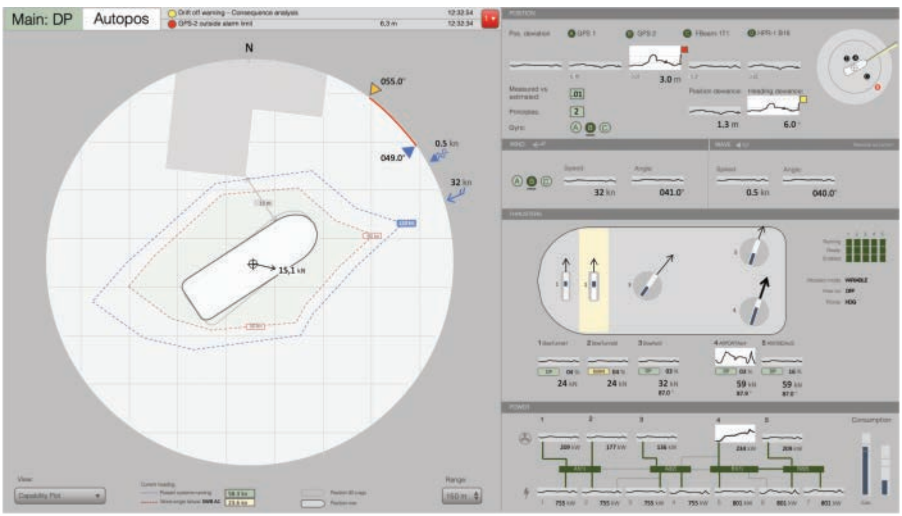

FIGURE 15.9 Possible overview display design – off-normal situation with multiple disturbances. (From Hurlen & Bye 2020.)

subjects may be inclined toward agreeing or being overly positive to the ideas presented to them. We sought to counteract this effect by encouraging subjects to freely express any views they had and by asking them to elaborate on their input as well as give practical examples from their own experience, which all of them did. No compensation was offered for their participation.

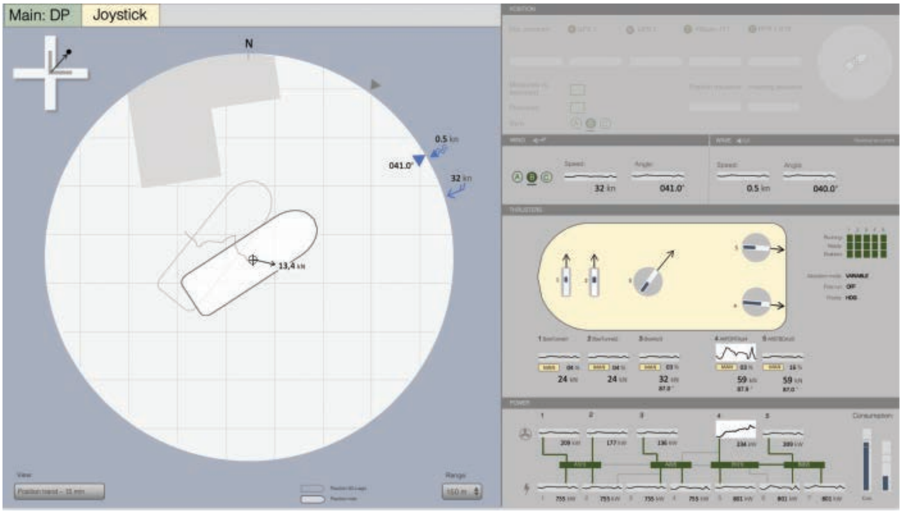

FIGURE 15.10 Possible overview display design – autopos mode is disengaged (return to joystick mode). (From Hurlen & Bye 2020.)

Feasibility of the Fixed Overview Display Concept – Does the Idea Seem Promising?

Three participants found the idea very promising, the fourth was somewhat doubtful about its potential for success. On the supportive side, they stated that having a fixed screen giving them a broad overview could be very useful: “I have always wanted something like this”. “What would do the most related to HMI is to have an overview display that is intuitive, others can be used for going in-depth”. “One place to cast a glance and see that everything is ok.” The content should be fixed, because “…when the alarms screams and it gets busy one needs to bring up screens and information that covers the things you really want [to see]. There are more alarms during bad weather and that’s when things go wrong”. They said that introducing a fixed display with information that is useful across most, if not all, situations would likely be possible to realize and that the mock-ups presented seemed like a good starting point for design. The participants thought that an overview display would be possible to fit in most current vessel types, but more easily on rigs than, e.g., supply vessels because of available space limitations. One stated that on a rig he would gladly dedicate two 50 in. displays for overview information in addition to the three 27-in. screens he is currently using for DP. Another pointed to the paper-based checklist that DPOs go through when starting their shift as a promising starting point for content selection, stating that “if I had a setup with all the things in the checklist I would always have it up.” Some speculated that an overview display might be useful not only for the DPO but for the rest of the bridge crew as well as for visitors (a possible measure for addressing the “Private HMIs limits shared situation awareness” challenge mentioned earlier). In this case, one might consider including non-DP related content also to create a more comprehensive overview for several bridge systems. This would need to be aligned with the needs of the DPO, possibly duplicating the display in several locations. The concerns were mainly related to the fact that information needs vary across circumstances, thus the DPOs need to be able to reorganize their screens. One of the interviewees felt that if there is an inexperienced DPO on duty, the captain should take an active role in dictating HMI layout arrangements.

Critical Success Factors

Participants agreed that the design should be clear and as simple as possible, with great emphasis on early warnings and deviations from expected normal states. The display should not feel cluttered, there might be a pitfall to include too much content that is "nice to have".

Ideas for Improving the Sketches Presented

One commented that perhaps wind presentation could be displayed to more clearly announce changes in strength and/or direction, e.g. could the wind arrows change color to yellow when it is increasing. Many lower level components could perhaps be presented using a collective "traffic light" to enrich display content while saving space. Using trended information as extensively as in the sketches seem promising, but they should not be too small – the alarms should be more clear. One speculated that maybe it would be a good idea if some information could be brought up by the user based on the situation, such as the capability plot (the sketches in Figures 15. 8–15.10 actually indicates the possibility of selecting among predefined "views", located at the bottom right). If a vessel is on Posmoor(atar) – a combination of DP- and anchor-based position control – more information related to this should be found on the display.

Other Input or Suggestions

All participants stressed the importance of improving the alarm situation. An overview display should acknowledge this challenge, aiming in its design to further help DPOs notice and correctly diagnose various warnings and alarm situations. Several of the participants were of the impression that DP is utilized more and more in the petroleum domain. Some also expressed concern about management (on shore) pushing operations too far, reducing the safety margins in order to maximize profits.

CONCLUSION AND FURTHER WORK

By analyzing DP-related incidents and interviewing experienced DPOs, captains and instructors, we have found that there is a potential for making changes to the HMI design in order to improve sensemaking. We have found that the challenges DPOs face are similar to the ones operators in other safety-critical industries are experiencing, so there are apparent opportunities for the maritime domain to learn from how they are being addressed elsewhere. In this work, we have looked to HMI and control room design in the petroleum and nuclear domains in particular for inspiration and propose introducing a fixed overview display as a supplement to existing HMIs as a feasible design measure for improving SA and sensemaking for DPOs. Current DP systems are typically designed in a way that let operators arrange their screens quite freely, leaving them vulnerable to overlook important information when unexpected situations occur – which they sometimes do and often quite rapidly. This study indicates that to introduce a well-designed fixed overview display can give DPOs an at-a-glance system overview regardless of the situation, enabling them to quickly detect, understand and counteract developing off-normal situations. On existing vessels, it might be more feasible to introduce such displays on construction and productions vessels (rigs) than on e.g. cargo vessels due to space limitations.

This has been an exploratory study with relatively few user participants, thus findings are far from conclusive. Still, the results provide motivation for DP systems developers to question one of the fundamental design choices related to HMI design – display reconfigurability versus fixed content presentation. The design proposals presented in this study are likely a good starting point for further user- and performance-driven research and development.

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