Sensemaking in high-risk situations. The challenges faced by dynamic positioning operators

Lars Hurlen
Digital Systems, Institute for Energy Technology, Norway. E-mail: lars.hurlen@ife.no

Ann Britt Skjerve
Digital Systems, Institute for Energy Technology, Norway. E-mail: ann.britt.skjerve@ife.no

Andreas Bye
Digital Systems, Institute for Energy Technology, Norway. E-mail: andreas.bye@ife.no

Dynamic Positioning systems (DP-systems) are becoming increasingly ubiquitous in the maritime domain and is utilized for station keeping in a wide variety of operations, such as drilling and well operations, cargo loading, diving operations, cable and pipe laying. A dedicated Dynamic Positioning Operator (DPO) on the vessel bridge is responsible for controlling this system when it is being used. Accidents and near-misses reports indicate that the sensemaking of DPOs is not always successful. In this paper we investigate the challenges facing such operations from a sensemaking perspective, analysing incident reports and interviewing DPOs to identify areas where improvements could be made to avoid incidents and accidents. Our analysis points in particular to three areas causing challenges: 1) Long periods of "rest" followed by sudden and sometimes unfamiliar shifts in risk-picture that require a fast response, 2) surprising vessel behaviour during certain DP modes, mode transitions and degradations in the DP system, and 3) limited possibility for practicing sensemaking in safety-critical situations, as these situations rarely arise.

Keywords: Dynamic Positioning (DP), Dynamic Positioning Operator (DPO), HMI, training, safety critical situations, incident analysis.

1. Introduction

The maritime sector is increasingly being automated. Vessels and rigs applied within the petroleum industry commonly use automatic systems, i.e., DP-systems, to uphold their position during critical operations, such as loading and off-loading goods at sea and drilling operations. DP-systems uphold positions by controlling thrusters, rudders and propellers, based on information from a variety of sensors and calculations.

A dynamic positioning operator (DPO) is the navigator operating the DP-system. The overall tasks of a DPO is to plan its scheduled activities, set-up the DP-system, monitor the system's activity and intervene with corrective actions, if needed. To establish a basis for deciding how and when to intervene when a critical situation arise, the DPO needs to make sense of the situation at hand.

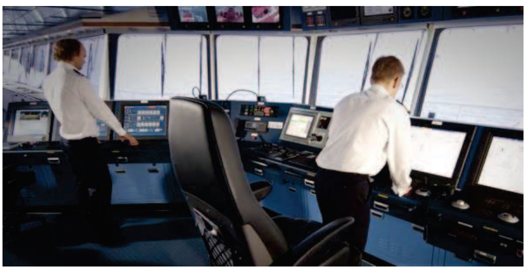

Figure 1 A modern ship bridge, here with DP-systems to the right (Kongsberg Group, 2013)

Sensemaking has been defined as "… a process prompted by violated expectations that involves attention to and bracketing cues in the environment, creating intersubjective meaning through cycles of interpretation and action, and thereby enacting a more ordered environment from which further cues can be drawn" (Maitlis and Christianson, 2014, p. 67). Sensemaking has some clear overlaps with "situation awareness" (Endsley & Jones, 2012), a term more commonly used in HMI design settings.

Accidents and near-misses reports indicate that the sensemaking of DPOs is not always successful (Dong, Vinnem & Utne, 2017), a finding which constituted the basis for establishing the SMACS project (SINTEF, 2018). The present study is a part study within the SMACS project.

The purpose of the study was to capture factors that challenge DPOs possibility for sensemaking in high-risk situations. In this study, we conceive a high-risk situation, simply as a situation, which is likely to result in an incident or accident at sea, stemming from lack of vessel

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control during DP operations. It is conceived as the result of a progressively weakened state of system safety.

The major contribution of this paper is the broad approach to data collection that is taken (described in section 2), the “sensemaking” perspective on data analysis, with a particular focus on training and Human Machine Interface (HMI) issues, and the links made to relevant findings from related safety-critical domains, such as nuclear.

2. Method

We have utilized lessons learned from event reports as well as cases in other studies. Data has been collected from two observations of DPOs engaged in simulator training, two semi-structured interviews with training instructors and experienced DPOs. These were conducted during five days visit to a training centre, in between observations of training sessions. Afterwards, two highly experienced DPOs were interviewed. Data has also been collected in Equinor’s Captain’s forum, providing data through thematic group discussions. 100 captains participated in the forum that is the basis for these data. After data collection, we have organised the data according to challenges to sensemaking.

3. Introduction to the domain

3.1 *DP Functions and operator tasks*

The DP system performs automatic vessel position and heading control. The system utilizes data from the vessel’s thrusters and a set of available reference systems, such as satellite GPS information, hydro acoustic position reference systems, radars and wind sensors, to update a mathematical model that keeps the vessel in a predetermined position. This position can be defined either in absolute or relative terms and is used for operations ranging from floating petroleum rigs to diving jobs and underwater cable laying. DP-systems are safety-classed 1-3 according to the amount of technical redundancy/robustness offered, and various operations are classed according to estimated risk.

DP systems can be used in a variety of modes, including full “autopos” mode, any combination of vessel movement control along its key axis of movement (surge, sway and yaw) and manual (joystick) mode. The autopos mode include a number of variations, such as “follow target”, “auto track” (path following) as well as station keeping. Also, different control strategy modes can be selected, such as “high precision” or “relaxed” control, varying thruster forces and the resulting power consumption and stress put on machinery. Different reference systems can be selected for input to the DP system, alarm and warning levels can be adjusted, and propulsion systems selected for use by DP. It is the task of the DPO to ensure that all of these together with the DP system itself is operative and fitted to the situation at hand.

The overall DPO tasks and phases of a DP cargo operation with undesired event can be described as follows, see **Error! Reference source not found.**:

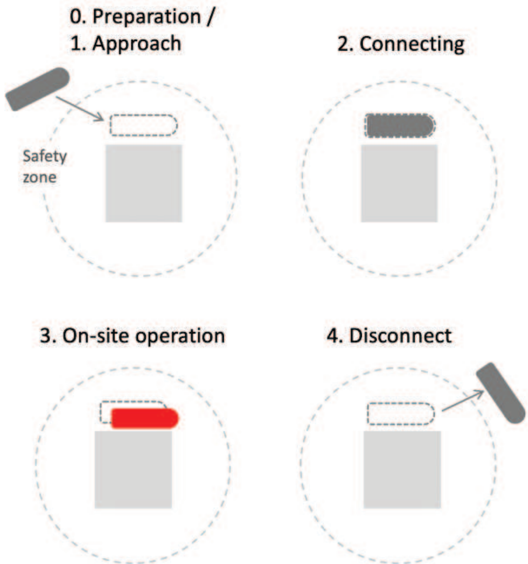

Figure 2 Phases of a DP-operation, with undesired event

0) Preparation for DP operation

- Distribute tasks and responsibilities
- Go through «DP-readiness» checklist
- Go through possible risks and plan how to respond in case they occur (extended team)
- Get permission to enter safety zone from installation

1) Approach

- Navigate to determined position

2) Connecting

- Select & activate reference systems
- Select warning and alarm limits
- Select DP mode

3) *On-site operation (with high-risk situation)*

Station keeping:

- Monitor position and environment status
- Adjust position as needed
- Adjust reference system input to DP as needed
- Manage deviations/alarms/faults
- Abort mission if needed

Event handling:

- Understand situation and share/coordinate with team

- Fault analysis
- Repair/mitigate if possible
- Decide whether to change DP mode, take over manually, and/or abort mission if the high-risk situation prevails.

4) *Disconnect*
- Abort mission
- Change DP mode / settings
- Navigate out of safety zone
- Repair/mitigate if possible
- Decide whether to resume operation

Our analysis indicates that even though other types of DP-operations, such as petroleum rigs, cable laying and diving operations are different in nature, the overall phases and tasks are largely overlapping.

While all phases outlined in **Error! Reference source not found.** are safety critical, undesired event handling is regarded as the most challenging for the DPO because of the extremely limited time that may be available for understanding the situation and for planning and executing a response. Such situations may also involve rare tasks for which the DPO has little training and experience.

3.2 *DP Human Machine Interface (HMI)*

There are a handful different DP system vendors worldwide, with Kongsberg Maritime as the most commonly used. The Kongsberg "K-Pos" DP HMI consists of an operator panel with physical buttons for mode, thruster and reference system selections, a trackball and joystick and a number of dedicated screens – two or three seem to be the most common configuration. The layout of the graphical HMI is highly configurable, with a number of "tiles" where users can choose which content and graphics to display (see Figure 2).

The DPOs we interviewed highlighted the position of the vessel, status of reference systems, status of thrusters and power systems to be the most critical information to monitor during a DP operation. In some situations they also rely on a "capability plot" – a real time graphic that calculates the worst single failure and displays the resulting station keeping capability in current weather conditions, supporting the DPO to make vulnerability assesments and adjust e.g. the vessel heading to minimize risk.

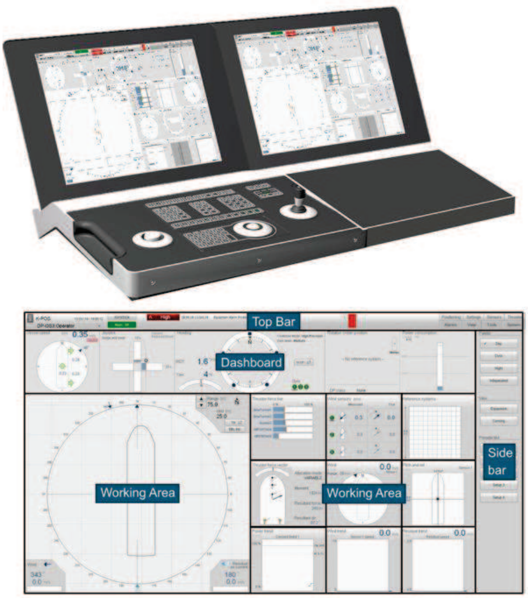

Figure 2 Configurable Kongsberg DP HMI "K-Pos", two screen setup (Kongsberg Maritime, 2014)

4. Results

4.1 *Contribution of human and organizational factors to DP incidents*

4.1.1 *Frequency of DP-incidents*

Serious DP-related incidents are relatively rare. The International Marine Contractors Association (IMCA) has collected undesired station keeping events since 1994. 2977 to 3911 annual hours of DP operation between events is reported for the years 2015 to 2018. In 2018, a total of 238301 hours of DP operation was recorded for 100 member vessels, which together reported 147 events (IMCA, 2019). Out of these, 24 were "incidents" (loss of DP capability), 82 were "undesired events" (loss of redundancy or compromised DP ability) and 42 were "observation reports" (no effect of DP capability but worth sharing).

4.1.2 *Contribution of "human errors" to DP incidents*

Figure 3 shows the main causes of events synthesized for the period 2004 to 2013 (IMCA, 2016). We see that the most frequent causes are technical in nature, while "Human error" is identified as the main cause in between 5 and 25 % of the events annually. "Operator error" is also

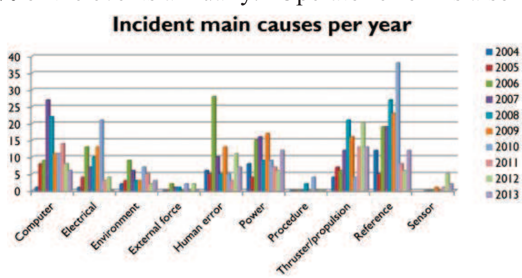

Figure 3 DP incidents by category reported to IMCA, 2004-2013

often identified as secondary cause in a considerable number of them.
To get a sense of the type of events reported to IMCA, in 2018 the following six DP incidents "human error" was found to be the main cause:

1) Accidental activation of DP standby button whilst in Automatic DP;
2) Miscommunication or miss understanding of move request;
3) Thruster loss led to incorrect operator actions resulting in drift off;
4) The hose end hawser went under the starboard propeller and parted;
5) The DP log book had been placed on the DP desk and led to the mode change being selected inadvertently;
6) The decision to alter heading was made too late leading to the vessel being unable to maintain position (IMCA, 2019)

In a study of drive-off incidents on the Norwegian Continental Shelf (NCS) in the period 2000 to 2015 (Dong, Vinnem & Utne, 2017) found that "… no accidents/incidents were a result from single technical failure or human action, while seven out of nine accidents and incidents were due to a combination of technical, human, and organizational failures". The incident reports point to human factors related issues such as lack of training/experience with the situation at hand, lack of procedures, procedures that were not followed, poor alarm management and presentation, important information that were available in the HMI but missed by the DPO, confusion during DP mode changes, and slow response time probably due to lack of sufficient situation understanding.

Looking for characteristics of critical incidents in DP Martinsen interviewed 42 DPOs and analyzed 24 incident recollections (Martinsen, 2013). The most common theme mentioned by the informants was "situation awareness" (SA), (ibid, p. 17). This awareness seems to arise from a combination of sources: Knowledge of current operative activities on the vessel, shift handover information, shift logs, ongoing collaboration with the operating team at large, information that is immediately visible on the bridge and out of the windows, and information provided by the DP-HMI.

As described above, many unexpected events are reported. There are not many attempts to try to analyse the safety by apriori detailed analysis of plausible, possible, or even "impossible" events. Probabilistic safety analysis does this, and the part that analyses the human actions in such events is called human reliability analysis (HRA). In the development and adaption of HRA for the petroleum and maritime industries, the project called Petro-HRA (Bye et al., 2017) did a test case on DP for a drilling rig. The main question is: "Which factors impact the operators' possibilities to mitigate a critical situation, and to which extent does this impact safety?

In the test case for this Petro-HRA method, the scenario chosen was a sudden drive-off of a DP controlled drilling rig due to errors in the propulsion system. This is a highly unlikely situation to occur, but should it occur, it places extreme urgency requirements on the DPOs to evaluate the situation and to cut the drill string in time, in order to save the well and prevent blowout. This kind of situation on an oil rig is slightly different from DP operation of supply vessels, however, the required task performance in critical situations have many similarities and learning points.

The test case describes a thorough task analysis (ibid, p. 100-110) for this case, where the main point is to detect the drive-off, stop the rig and disconnect from the wellhead in time. The factors found to mainly impact the DPO's performance were, as mentioned under "human error reduction" (ibid, p. 126-127): HMI, training and procedures. The HMI was in general adequate for diagnosing the events, but the "layout of the operator workstation for stopping the thursters was not optimal" (ibid, p. 126). They were not trained on this specific event, and there were no specific procedures for the drive-off or similar events.

In the following sections we point to trends in Human Factors related DP-challenges we see in the material analysed, with emphasis on those we consider related to sensemaking and/or situation awareness.

4.2 *Alarms/alerts – too many or too few*

In several of the incidents recorded in the IMCA database it is noted that alarms that should have come from the system was missing. In our interviews, DPOs also points to alarm overload as an issue that in certain situations contributes to confusion, distraction and loss of situation awareness. Reports from the NCS also point to both missing alarms and flooding of alarms as contributing factor reducing DPOs ability to handle incidents properly (Dong, Vinnem & Utne, 2017).

Most complex and safety-critical industries Institute for Energy Technology have worked with struggle with alarm-related issues, and even though a well tuned alarm system is considered crucial for safety it remains a challenge. Success stories is most often associated with a continuous, dedicated effort over time.

A recent Norwegian joint industry project with participants from all areas of the maritime design chain looked specifically on alert management on the bridge and suggest improvements in similar areas: "redefining roles and responsibilities of the stakeholders involved in alert management system design, reducing the number of alerts that reach the bridge, and improving the presentation of alerts (van de Merwe, 2016).

In summary:

- *Alarm presentation*. Numerous alarms in lists with much text to read seem ineffective as the only means of informing operators that need to make decisions fast.
- *Important alarms are missing or not salient enough*. Even though alarms are presented in the HMI they are not always noticed, especially if there are many of them.
- *Rare alarms are not understood*. Some alarms occur so rarely that operators struggle with their meaning even if they notice them.

4.3 *Mode surprises*

In several of the events reported to IMCA, the DPO decides to disconnect the DP system to take manual control of the vessel, switches mode and is surprised that all thruster setpoints are nullified, leading to a surprising situation where longer time than desired is spent gaining control of the vessel. In one of the incidents reported on the NCS (Dong, Vinnem & Utne, 2017) the DPO is surprised of how the vessel behaves when changing from "weather wane" to "autopos" mode, and in several others it seems to be challenging for the DPOs to determine when a change to manual operation is the most appropriate action. In one incident, the DPO put the DP in "standby" mode but forgot that to put it back in "autopos" mode it is necessary to first go to "manual" (IMCA, 2007 , p.29). There are also examples of inadvertent mode changes caused by leaning over or putting things on the mode buttons (IMCA, 2019).

During our time spent in a DP simulator, we noticed that there may be useful cues lacking in the HMI indicating either that the DP model is degraded, or when there is a discrepancy between measured and calculated values. A total loss of DP capability may also cause confusion. A simulator trainer had experienced DPOs noticing the alert stating that the DP model was corrupt and manual operation was required. After the alert had been acknowledged and disappeared from the screen, the DP system appears normal in the HMI, and the DPO erroneously continued as if DP was operational while in reality he was drifting. One DPO participating in the captain forum stated that "many are not able to dock manually, it is getting harder than it used to be also – the vessels are made for DP".

Endsley & Jones also conclude that the proliferation of modes tend to make systems more complex, and thus reduces the "ability of operators to develop a good mental model of how the system works in all of its possible modes" (Endsley & Jones, 2012, p.188).

In summary:

- *Changing from one mode to another may surprise the DPO*. This issue is clearly related to procedure quality and training (and most often reported as such), but also involves deeper system design issues related to a proliferation of modes that are not intuitively understood and can be detrimental to Situation Awareness. In these situations the DPOs may well have understood which mode they were in but struggle to anticipate how the DP behaves during mode transitions.
- *Noticing and handling a degraded or loss of DP capability*. Determining when and how to intervene "manually" seem challenging in certain situations, and possibly the HMI could do a better job of communicating relevant and accurate information about the degraded system states. It may be worthwile to further investigate what kind of alerts are most effective in such situations.
- *"Joystick mode" can be challenging to operate*. In some cases a manual takeover may be challenging, even if one understands the situation.
- *Inadvertent mode changes*. A few incidents reported to IMCA are caused by DPO putting an item on, or leaning over, the push-buttons used for mode selection, inadvertently changing DP mode.

4.4 *Critical information hidden from view*

A recurring HMI-related topic from DP interviews is related to the information DPOs base their situation awareness on in a critical situation. One stated that "I had all the information, but I only used the thruster screen" (Martinsen, 2013, p. 76). Another DPO we interviewed said that "if the information is not already on the screen it will not be used", considering three dedicated DP screens a minimum for displaying all the information required for safe rig operations. Operator "tunnel vision" and reluctance to perform interface management tasks during stressful situations is a well known issue in other industries, e.g. in nuclear control rooms (O´Hara & Brown, 2002). The cause may be both HMI-related, such as hiding or making critical information difficult or laboursome to retrieve, and poor attention management on the part of the operators.

Of the 42 incidents recollections analysed in the Martinsen study 19 were unexpected, and in five cases the DPO had no previous experience with the particular situation (Martinsen, 2013, p.18-21). When individual DPOs are responsible for selecting and arranging the information visible on the DP screens, adjust warning and alarm limits and selecting position reference systems input specifics, critical information may be hidden from view and not used when an unforeseen situation occur.

On a related note, IMCA also notice a negative trend where DPOs select only one position reference system principle (usually satellite GPS), where minimum two different principles is considered best practice (IMCA, 2019).

4.5 *"Private" HMIs limits shared SA*

When the DP interface is targeted towards the DPO exclusively, it can be difficult for colleagues on the bridge to determine the state and activities related to this system. This may reduce team situation awareness in critical situations. Participants in the "captains forum" stressed the importance of the captain assessing the experience level of the DPO in order to calibrate his own involvement to ensure safe operations. One said he liked to bring up the DP screen displaying the heading and setpoint of the vessel on one of the monitors that he could see.

4.6 *Deskilling*

Several of the people interviewed pointed to the risk for degraded ability to manually manoeuvre vessels when navigation functions are increasingly automated. When automation increases, the DPOs are provided with fewer possibilities for practicing navigation in the vicinity to other ships or installations. A trainer described how he had witnessed DPOs working on rigs that were unable to take over from the DP system and navigate manually. A DPO explained that the rig could be located at the same position for up to three months. He continued "… and then you are left monitoring. Except for dealing with alarms on the wind sensors, as one of these will always be sheltered, the work is very monotonous." Another stated: "There can be years between something happens."

Bainbridge (1983) emphasised that training is needed to prevent deskilling. She saw the relationship between high-level of automation and the need for training as one of the ironies associated with automation: "Perhaps the final irony is that it is the most successful automated systems, with rare need for manual intervention, which may need the greatest investment in human operator training." (ibid., 777). DP systems are a good example of such "successful" automation in that there are relatively few incidents, and that for many types of operations the DPOs have little to do besides monitoring the (largely autonomous) system for long stretches of time.

4.7 *Out-of-the-loop*

As described in section 4.6, DPOs explain that when working on rigs, the job may be rather monotonous. An operator described how DPOs may go into a kind of mental "rest modus" where they observe, what is going on, without being genuinely alert. This type of description points to the risk that DPO may from time to time be out-of-the-loop (Kaber & Endsley, 1997), due to too low degree of participation in the operational tasks, i.e., too low workload. This corresponds to the findings in vigilance studies, which have long shown that "… for even a highly motivated human being to maintain effective visual attention towards a source of information on which very little happens, for more than about half an hour" (Bainbridge, 1983, p. 776). Out-of-the loop performances is associated with a loss of situation awareness (Endsley & Kiris, 1995).

The out-of-the-loop performance may remain unnoticed unless a high-risk situation enters the picture. A DPO expressed it like this: "99% of the time, nothing happens, and then all of the sudden there's a crisis, and during crises situation you have very little time to decide what to do, from seconds to minutes. This is challenging." When a crisis situation threatens to arise the DPO may strive to return to the loop. There may be alarm overload, as described in the section 4.2. Alarms that occur rarely may be challenging for the DPO to understand, which implies that he has to read the associated alarm text to make sense of the situation at hand. The challenges to the DPOs sensemaking that follows from facing rarely occurring alarms, may likely be similar for all other rarely occurring indicators in the HMI or elsewhere during a crisis situation. Unless DPOs practice the skills required during crisis management, there will be a risk that the skills required to handle these begin to decay (see section 4.6). This may also be the case for teamwork skills. Skjerve and Holmgren (2018a) found that within nuclear power plant operators, around 19% of the teamwork skills required by nuclear power plant operators were mainly applied during emergencies.

All the unusual stimuli need to be processed and the time frame may be limited. Based on operational data, Chen and Moan (2004) identified lack of time for recovery actions as a critical factor in DP emergency operation. For this reason, the DPO experiences reduced ability to solve complex problems due to the influence of negative stress reactions such as selective perception, stereotype thinking, irritability, reduced search for information (cf. Weisaeth, 1985), which may also impede collaboration and communication. In the latter case, the DPO may run the risk of being out-of-the-loop, because of too high levels of workload.

5. Discussion

5.1 *Dealing with unexpected situations*

The case study from Petro-HRA described above on improbable situations could have been labeled unexpected critical situations. However, one might say that if it is analysed, and especially if it is trained for, it is no longer unexpected, although it is highly improbable. (In the mentioned case they were not trained for this event though). The fact that the methodology in the test case includes scenarios, known or hypothetical, gives a hint that the situations are at least thought out beforehand.

It is important to make analyses based on scenarios that can happen or are at least plausible to some extent. They give a detailed picture of which factors that help or hinder operators to do a good job in specific situations. The details of the scenarios enables analysts to get a good picture of details of HMI, procedures and training that is relevant for the situation. However, there might be many situations that are not covered by apriori defined scenarios.

One strategy may be to focus training more on unforeseen events and the underlying principles that govern the processes system, controlled by the operator , instead of training on procedures for known or hypothetical events. Skjerve and Holmgren (2018b) demonstrate such a methodology *Coaching for Improved Ability to Handle Unforeseen Events* (CIAU) . The method is based on the Adaptive-Expertise theory (Hatano and Inagaki, 1986) that differentiates between training routine expertise for foreseen events and training adaptive expertise for unforeseen events. CIAU is a guided-discovery method (see e.g., Smith et al., 1997). It is used critical thinking (e.g., considering "why and how" each step of a procedure works), experimentation and exploration to promote development of adaptive expertise, which is the ability to handle non-standard tasks. The adaptive expert has a conceptual understanding of the domain. He is able to decompose, transfer and flexibly apply his or her knowledge in novel situations (Bransford, Brown and Cocking, 2000). CIAU may be a good starting point for training sensemaking for critical situations.

5.2 *Possible measures to improve sensemaking*

The challenges described in the previous point to several areas worth exploring further to improve sensemaking in DP operations, listed below.

Improving sensemaking to reduce the risk for out-of-the-loop experiences:

- HMIs and work practices that level out workload associated with DP operations: Increases workload (involvement) during normal operation and reduces workload during crisis situations.
- Adjustments to the DP mode structure and associated HMIs with the goal of reducing risk of mistakes and misunderstandings during DP degradations, mode selections and mode transitions.
- Improved alarm structure and presentation, making sure real threats are sufficiently salient in the HMI and communicated effectively.
- Ensure that "at-a-glance" elements that support situation awareness are always present in the HMI (possibly to the whole team on the bridge), regardless of the situation and the way the HMI is configured by the DPO.
- Better alignment of "directional" graphical elements in the HMI. Directional forces affecting the vessel movement (such as wind, current and thruster forces) are represented in a number of different ways in the HMI, using graphics oriented in different directions related to the vessel on the DP screens, as is the vessel itself. While this has not been raised as an issue in the materiel we have analysed, it is easy to imagine that it could contribute to operator errors caused by reduced sensemaking in stressful situations, and could be worth looking into.

To reduce the risk for deskilling one might improve the "simulation mode" featured in some DP-systems to visualise how the factors monitored by the DPO impact each other, and to practice challenging DP-scenarios during "slow" periods onboard. The purpose would be to allow operators to develop their knowledge and skills in order to support his ability for making successful decisions during crisis operations.

6. Conclusion

At this time, our findings point to three overall factors causing challenges for DPOs: 1) Long periods of monitoring that may bring the DPO into what an interviewee characterized as a "rest modus" suddenly interrupted by the need to deal with a critical situation within a short time span, requiring a fast change in modus operandi associated with sensemaking. This finding points to the need for identifying elements that promote the DPOs ability to uphold continuous, detailed sensemaking processes. 2) A DP mode regime that in certain situations confuse the DPOs. DP systems offer quite a few modes, and variations of them, suited to different operational variations, and our findings indicate that DPOs are sometimes surprised at how the DP system behaves – particularly when transitioning between different modes. 3) Limited possibility for practicing sensemaking in safety-critical situations, as these situations rarely arise. This underlines the need for providing more training possibilities and for organizing every-day work to facilitate both competence refreshment and learning.

The outcome of the study will be applied within the SMACS project to assist in identification of training needs, needs for adjustment in the human-system interface associated with DP-system and work practices, to promote the possibilities and abilities of DPOs to readily make sense of situations at hand at any given time.

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