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Autonomous and remotely operated service operation vessels in wind farms

A study exploring the practical utilization of autonomous and remotely operated service operation vessels during dynamic positioning operations in offshore wind farms.

Master thesis in Maritime Management

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Abstract

In response to the societal pressures for developing green energy sources to address the wicked problems of climate change, the maritime sector has witnessed a rapid development of offshore wind farms, particularly in Northern Europe. Part of the operational strategy to improve the opportunities for exploiting wind-based energy harvesting, are investments in digitalization and increasing levels of autonomous technologies. To maintain a safe and reliable operation and environmental protection it is critical that these technologies can be managed by human operators.

This thesis examines the practical deployment of automation-based technology during dynamic positioning operations within wind farms according to dynamic positioning operators. An ethnographic study was conducted to map goal-based tasks during dynamic positioning operations within a wind farm. Dynamic positioning operators were requested to reflect on the practical possibilities of deploying automation-based technology to improve or substitute DP tasks during semi-structured interviews. One researcher and three developers within autonomous and remote steering were also interviewed using a semi-structured approach to obtain their take on human-machine interaction issues. A thematic analysis of the interviews detected the main attributes of tasks that could be allocated to autonomy or remote handling respectively. These findings were compared to previous research and deliberated in the discussion section. When human life is at risk, the response time is limited, and the outcome uncertain a task was considered high-risk. Primarily, these are tasks conducted close to installations and tasks relating to emergency response. There are several methods and aids to improve human-machine interaction issues, enhancing the use of autonomous and remote operations within wind farms. Nevertheless, the specific capabilities of humans in what is defined as high-risk situations should not be undervalued. Therefore, high-risk tasks are only practically deployed to any other party than a human under the circumstance that there is a human on board the vessel, monitoring with sufficient situation awareness and competence to take control when needed.

Key words

Maritime autonomous surface ships, autonomy, remote operations, shore control center, dynamic positioning, offshore wind farm, human-machine interaction.

Preamble

During a winter vacation in Sweden, we rented a station wagon made by Volvo. It was a brand-new car, including all the technology that implies. Obviously, we had to try it out. We activated the lane keeping aid and let go of the steering wheel. Due to an ice coverage on the road, the lane keeping aid could not keep track of the road markings. The aid steered the car perfectly up to the point where the snow covered the road marks. The aid suddenly steered us straight ahead regardless of the road bend, almost leaving us crashing into a tree in the middle of nowhere. Now I might blame my husband for being bold or the lane keeping control for its flaws. However, there is a greater meaning of this story: whether machines and humans are compatible with one another or not. We are currently facing more advanced technology in our everyday life, and it is of great importance to seek an understanding of all aspects that such an introduction can inflict on us.

List of Abbreviations

AI	Artificial Intelligence
COLREG	International Regulations for Preventing Collisions at Sea
DP	Dynamic Positioning
DPO	Dynamic Positioning Operator
EU	European Union
FRB	Fast Rescue Boat
HMI	Human-Machine Interaction
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
IOSS	Intelligent Operator Support System
MASS	Maritime Autonomous Surface Ships
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
OWF	Offshore Wind farm
PMS	Power Management System
ROV	Remotely Operated Vehicle
SA	Situation Awareness
SAR	Search and Rescue
SCC	Ship Control Center
SDPO	Senior Dynamic Positioning Operator
SOLAS	Safety of Life at Sea
SOV	Service Operational Vessel
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
USV	Unmanned Surface Vehicle

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1 Introduction

The aim of this thesis is to examine the possibilities of deploying automation-based technologies to substitute goal-based Dynamic Positioning (DP) operations by transferring the control from a vessel's crew to an autonomous system or a ship control center (SCC). Through a set of interviews with dynamic positioning operators (DPOs), academia and developers within automation and remote operations, the practicality of obtaining a level of automation and remote handling within DP operations is explored.

1.1 Background

Klaus Schwab (2016) describes how the world is about to face the fourth industrial revolution; characterized by rapidly fusing physical, digital and biological fields. Autonomous vehicles are identified as a physical megatrend. Schwab (2016) emphasizes the importance of continuous learning and adaptation during the fourth industrial revolution, due to the increasing rate of technological change.

1.1.1 Legislative matters enabling autonomous and remote shipping

According to a report written by the World Maritime University (2019), adoption of new technologies tends to be slow within the maritime sector. The legislative framework is not in place to enable autonomous shipping internationally. However, autonomous solutions can be tested regionally, legislatively enabled by national governments or bilateral agreements between adjacent countries.

In 2017 the International Maritime Organization (IMO) adopted Strategic Directions for the Organization, which included integration of new technology without sacrificing or pushing the current levels of safety, security, or environmental matters. The Maritime Safety Committee (MSC) assessed if the IMO instruments were applicable for varying degrees of autonomy and how it would be appropriate to address Maritime Autonomous Surface Ship (MASS) operations through a scoping exercise. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and the International Regulations for Preventing Collisions at Sea (COLREG), among others, were two of the instruments assessed by the MSC (IMO, 2021).

In 2021 the IMO completed the scoping exercise pointing out the development of terminology and definitions, functional and operational requirements of an SCC, and defining the remote operator as a seafarer as key issues. Other identified themes and gaps include search and rescue,

firefighting, and maintenance. The committee concluded that the most favorable path forward would be to develop a goal-based MASS instrument, including functional requirements, corresponding regulations, and goals applicable for all degrees of autonomy (IMO, 2021).

1.1.2   The future seafarer and human-machine interaction issues

Seafarers must constantly learn to keep up with technological advancements. Besides maintaining their traditional skills, they need to develop new skills along with the ever-increasing technology (Chubb, 2017). Captain Chawla, P. (2015) points out human factor competences that are required by the future seafarer the upcoming two decades. Information distraction or overload of information can lead to failure of monitoring, which in turn will decrease the situation awareness. The ability to process large amounts of data and the ability to point out relevant and critical pieces of data are some of the skills needed. Closer integration between ship and shore systems will require seafarers to develop their teamworking and communication skills. Due to automation induced complacency, focus shifts to the importance of understanding the system and its limitations. The development of technology will enhance skills that helps seafarers manage change and learn continuously. Maritime Executive (2016) points out that over-dependency on technology and automation-induced complacency often affects the monitoring of automated systems. On the other hand, an automated system also decreases the load of information that must be processed by the operator.

1.2   Definitions

In this section the main elements of this thesis will be defined.

1.2.1   Dynamic positioning system

A DP system enables a vessel to control its position and heading by steering the vessel's propulsion through a position and control system (IMCA, 2020). By comparing a continuously updated mathematical model with the desired position and heading, the DP system calculates corrective thrust commands (Bray, 2015). The system is capable of controlling surge, sway, and yaw (yellow arrows), while compensating for environmental forces (red arrows) using various propulsion systems (green arrows) (Offshore engineering, 2022).
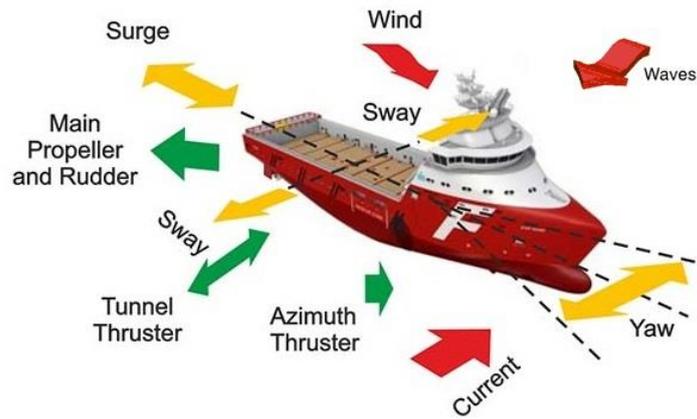
Figure 1. Offshore engineering (2022)

DP systems are considered highly automated systems and the intention of using these systems is to increase safety, accuracy, and reliability (TNO, 2018). The system was originally used on deepwater drill ships, since they were unable to keep position using other options, such as anchoring or jack-up. DP capability is now common on a wide range of vessels, such as diving, subsea, floating, production, storage and offtake, anchor handling, platform supply, drilling, accommodation, and passenger vessels (Bray, 2015).

A DPO is a certified operator of the DP system and is thereby qualified to operate and monitor the system (Bray, 2015). According to the guidelines of the International Marine Contractors Association (IMCA) (2016) one of the two DPOs on watch will be delegated the role as the senior dynamic positioning operator (SDPO). The SDPO is responsible for the navigational safety and is the lead DP watchkeeper while the DPO is the DP control system operator.

1.2.2 Offshore Wind farms

The first offshore wind farm was built in Denmark in 1991 (Environmental and Energy Study Institute, 2010). According to Wind Europe (2022) the offshore wind capacity in Europe was 28.4 GW as per mid-year 2022, expecting 160 GW offshore wind capacity by 2030. The offshore wind sector comprised of 123 offshore wind farms in 13 European countries mid-year 2022 (Wind Europe, 2022). The European wind energy association (2011) states that developing, maintaining, and decommissioning wind farms can be done using DP systems. These activities include vessels involved in survey, subsea, construction and maintenance.

1.2.3   Levels of autonomy

The Norwegian Forum for Autonomous Ships (NFAS) defined four levels of autonomy in their Definitions for Autonomous Merchant Ships: Decision support, automatic, constrained autonomous and fully autonomous (Rødseth & Nordahl, 2017).

The decision support level is defined as:

> "This corresponds to today's and tomorrow's advanced ship types with relatively advanced anti-collision radars (ARPA), electronic chart systems and common automation systems like autopilot or track pilots. The crew is still in direct command of ship operations and continuously supervises all operations. This level normally corresponds to "no autonomy"" (Rødseth & Nordahl, 2017, p.11)

The automatic level is defined as:

> "The ship has more advanced automation systems that can complete certain demanding operations without human interaction, e.g. dynamic positioning or automatic berthing. The operation follows a pre-programmed sequence and will request human intervention if any unexpected events occur or when the operation completes. The shore control centre (SCC) or the bridge crew is always available to intervene and initiate remote or direct control when needed." (Rødseth & Nordahl, 2017, p. 11)

The constrained autonomous level is defined as:

> "The ship can operate fully automatic in most situations and has a predefined selection of options for solving commonly encountered problems, e.g. collision avoidance. It has defined limits to the options it can use to solve problems, e.g. maximum deviation from planned track or arrival time. It will call on human operators to intervene if the problems cannot be solved within these constraints. The SCC or bridge personnel continuously supervises the operations and will take immediate control when requested by the system. Otherwise, the system will be expected to operate safely by itself." (Rødseth & Nordahl, 2017, p. 11)

The fully autonomous level is defined as:

> "The ship handles all situations by itself. This implies that one will not have an SCC or any bridge personnel at all. This may be a realistic alternative for operations over short distances and in very controlled environments. However, and in a shorter time perspective, this is an

unlikely scenario as it implies a very high complexity in ship systems and correspondingly high risks for malfunctions and loss of system." (Rødseth & Nordahl, 2017, p.12)

1.2.4 Ship control center

In this thesis an SCC is defined as a location on shore, on a ship or on a substation from which the ships of the wind farm are monitored and controlled depending on the applied level of autonomy.

An SCC operator is defined as a person who is responsible for monitoring and controlling one or more ships within the wind farm. Depending on the situation and task, a need for several SCC operators in different roles can arise, for example a captain, a navigator, an electrician, or an engineer. In this thesis only the SCC tasks corresponding to current DPOs tasks will be included.

1.3 Research question

The following research question will be considered in this thesis:

- How practical, from a safety of operations perspective, is it to deploy automation-based technologies to substitute or improve goal-based DP operations?

1.4 Limitations

Due to the limited number of interviewees working for the same company, in the same geographical area, and the uncertainty of the development of MASS technology and execution, this thesis cannot be regarded as representative for the autonomous or remote level of future DP operations within global offshore wind farm operations. All the interviewees are working or have been working as DPOs within offshore wind farms. This may not be representative of other DP operations. The SOVs in this study are assumed to have technicians or clients on board.

1.4.1 Levels of autonomy

DP itself is used as an example of an activity on the automatic level according to Rødseth & Nordahl (2017). Many DP operation activities are not related to the DP system itself, therefore, all levels of autonomy will be considered for each goal-based task. All goal-based tasks that are pointed out in this thesis might be fulfilled differently after transitioning from being controlled by a navigator to automation-based technology. However, the outcome should not result in a less safe, secure, and reliable DP operation.

1.4.2   Delimitations

Economic aspects, level of technological advancement, laws, regulations, guidelines, or other factors that might affect the advancement of MASS and DP operations will not be reviewed in this thesis.

2   Literature review

In this section, relevant findings from a collection of academic articles, papers, journals, and reports are presented. There is a lack of previous research regarding autonomous and remote DP operations within wind farms, therefore the literature review is focused on dynamic positioning, socio-technical issues, remote operations, situation awareness, trust, blame, skills, and adaptive support, which are related to conducting DP operations from ship and shore. The synthesis of the pertinent literature regarding operational skills is depicted in Figure 4.

2.1   Removing humans from autonomous systems

Lisanne Bainbridge wrote the article "Ironies of Automation" in 1983, discussing how automation can increase human error rather than decrease it. It is often assumed that substituting human activity with machine activity by introducing automation is simple (Woods & Sartes, 2000). Empirical data suggests that this is not the case and that problems with safety and performance can be linked to taking humans out-of-the-loop (Endsley & Kiris, 1995).

2.1.1   Safety

A human operator might be perceived as unreliable and insufficient by automation designers (Bainbridge, 1983). Sixty percent of all accidents in the shipping industry are due to human factors (SURPASS Project, 2012). However, as mentioned by Bibby et al. (1975), automated systems will to some extent stay human-machine systems since they are dependent on humans when it comes to supervision, adjustment, maintenance, and improvement. It is evident that some of the tasks mentioned will be replaced by automation eventually. Whether we like it or not, in a fully automated process, there will still be a trace of the human element, for example as the designer (Bainbridge, 1983). Hogg and Ghosh (2016) mention that accidents linked to humans will not be eliminated since humans will still conduct maintenance and calibration of the equipment and the vessels might be monitored by an operator at an SCC. They also point out that the unmanned vessel industry will face new challenges to maintain a safe operation.

2.2   Human-machine interaction

Whenever things go wrong, as they occasionally do, an operator can take control manually of an automated system. The irony in this case would be that there is likely little room for practicing those manual skills when the automated tasks are normally operated by the automated system. Even if an operator had long-term manual experience, skills deteriorate over time and knowledge from long-term memory tends to be effectively used only when practiced frequently. Gaining experience through a *trial* and *error* type of approach is also vital

for skill development when using an automated system. Operators with long-term experience as manual operators will eventually be substituted with operators without any manual experience (Bainbridge, 1983). Farrell and Lewandowsky (2000) suggest that an operator's performance declines when moving from being in control manually to monitoring the automation.

An operator will notice when there are abnormalities in what they perceive as their task, but they might not notice abnormalities normally seen as the task of an automated system. Especially if the system has proven to work effectively for a longer period of time. (Bainbridge, 1983). Furthermore, operators of intelligent systems often have a lower perceived risk than infrequent system users (Saffarian et al., 2012). The operator will likely only maintain a meta-level of the decision-making. Since a computer is working faster and taking decisions based on more dimensions and criteria than a human, the operator will be left monitoring if the computer is making "acceptable" decisions (Bainbridge, 1983).

In the paper "The seven deadly myths of 'Autonomous Systems'" several misconceptions regarding autonomous systems' ability to replace humans are presented by Bradshaw et al., (2013). When tasks previously done by humans are liberated by autonomous systems, new types of cognitive work are created for humans. They argue that humans are required to do more tasks faster often involving more complexity. It reduces the humans' ability to keep track, stay aware, and incorporate the alterations being done. Another misconception is that less knowledge is required. The human is excluded from the loop, and thereby lack sufficient context to make the correct decisions even with new skills and knowledge. They also emphasize that the human-machine collaboration is essential for such a system to be successful (Bradshaw et al., 2013).

2.2.1 Optimization

If a low probability event must be noticed, the operator should be given assistance or be noticed through alarms. When the operator is used to working with the automated system and accompanying displays, a major problem will occur when displays are no longer available to the operator in an emergency. Automatic control can also camouflage system failure by compensating for variable changes, which might only become apparent when the failure is out of control. When transferring to manual control, a systematic failure previously compensated for by the system, an operator will be caught off guard with a systematic failure that suddenly needs to be compensated for manually (Bainbridge, 1983).

Bainbridge (1983) discussed machine intervention on decision making, which includes the system to provide advice, assistance, error mitigation and sophisticated data representation. Thompson (1981) mentions the following four types of advices regarding a failure: possible underlying cause, comparative importance, possible actions and how to implement these. However, this will make the operator react slower and will not get any practice in taking independent decisions, and it will always be dependent on which information is presented and how this information is presented (Bainbridge, 1983).

2.3 Situation awareness

Endsley (1995, p. 36) defined Situation Awareness (SA) as 'The perception of 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'. It is necessary to maintain situation awareness to keep the operator in the loop and keep track of the dynamic situation (Porathe et al., 2014). An operator's ability to grasp and maintain situation awareness will be dependent on experience, attention capacity and ability to multitask, plan and prioritize. An operator will need to understand the equipment that they are using to interpret the information, thereby increasing situation awareness. (Endsley, 2012). Meanwhile, one study shows that humans have issues maintaining visual attention towards a source of information for more than half an hour (Mackworth, 1950). Bainbridge (1983) points out that it is complicated to take charge of an autonomous system or take decisions with insufficient situation awareness and manual skills. Gaining situation awareness takes time, and it can be challenging to maintain manual skills.

2.3.1 Ship sense and Harmony

In the article "From desk to field - Human factor issues in remote monitoring and controlling of autonomous unmanned vessels", Man et al. (2015), identifies human factor issues related to SCCs and the challenges in obtaining sufficient situation awareness to make appropriate decisions. The authors have drawn their conclusions based on the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project by the European Union (EU). The purpose of the MUNIN project was to check the feasibility of intercontinental voyages with autonomous vessels governed by SCCs (Man et al., 2015).

An officer on a vessel is constantly building situation awareness. However, it is still to be discovered how to help an operator build up situation awareness in an SCC (Man et al., 2015). The authors bring up the concepts of "ship sense" and "harmony". Ship sense is developed through experiencing the spatial movement of the vessel together with the vessel's inertial

performance relating to maneuverability. An officer makes decisions regarding ship handling based on ship sense (Prison et al., 2009). The vessel specific prerequisites (such as inertia and navigational instruments) and environmental prerequisites (such as personal prerequisites which includes knowledge, awareness, and experience) together make up "harmony" (Prison, Dahlman & Lundh (2013); Prison (2013)). An officer strives to obtain harmony between the environment and the vessel (Prison, 2013). When the operator is physically separated from the ship, he or she might face challenges building up situation awareness and creating harmony.

2.3.2   The three SA levels and the gaps

The three levels of SA used in the paper by Man et al. (2015) is perception, comprehension and projection as defined by Endsley (1988). When an operator perceives the elements from the overall context, level 1 SA is obtained. With the use of experience and theoretical knowledge an operator interprets the overall context, thereby obtaining a higher level of SA (2 or 3) which enables the operator to foresee situations. A comparative analysis of the study showed that there were four discrepancies in SA requirement (Figure 2) (Man et al., 2015).

The first discrepancy was found between the environmental prerequisites and the vessel prerequisites. When an operator and a ship are separated physically, the operator can only get an understanding of the environmental prerequisites based on information provided through the ship sensors. The second discrepancy was found between the environmental prerequisites and the vessel higher level SA. This implies it will be difficult for an operator to perceive contextual information and feel the movement of the ship. The third discrepancy was found between the vessel prerequisites and higher levels of SA. The operator would be dependent on information through input from navigational instruments to comprehend the environmental context and the vessel's inertial performance. The fourth discrepancy was found on the higher SA level. The physical and cognitive process might have changed compared to on board, even though the operator might have previous experience as an officer. Without training and adaption, the operator will face challenges to obtain higher levels of SA (Man et al., 2015).

Man et al. (2015) suggests a couple of solutions to the four gaps. The technology must be reconsidered to meet the needs of sensing objects and necessary data communications. The fourth and third gap will depend on the user's characteristics and operational requirements, which could be improved through training and adaptation as mentioned earlier (Endsley, 2011).
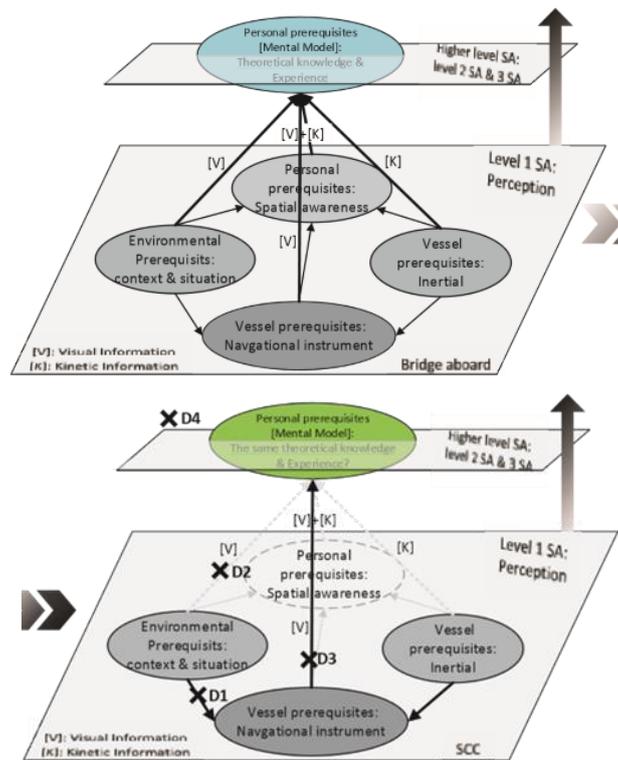
Figure 2. (a) tetrahedral model adapted from harmony (Prison, Dahlman, Lundh (2013); (b) four discrepancies are identified for further analysis (Man et al (2015))

During the trails, the system was not fully developed, leading to technical glitches. There was also a limited number of participants and scenarios accompanied by limited training. The results might have been different if the test had been conducted with a more developed system and trained interviewees. However, the results do point out where we might find problems in sociotechnical systems that should be examined before realizing MASS (Man et al. 2015).

2.4 Human factor challenges in the shore control room

Wahlström et al. (2015) did a study examining the human factor challenges which might impact future SCCs. They point out the following challenges for the SCC from existing studies: limited situation awareness, information overload, local conditions, and limited knowledge leading to communication challenges. Wahlström et al. (2015) did a literature review to look for human-machine interaction issues that have occurred in other workforces to examine challenges impacting future SCCs. According to Wahlström et al. (2015), ship sense should be transferred to the SCC, thereby limiting the consequences of not feeling and hearing the ship, engines, and weather (Wahlström et al, 2015).

In the car industry, automated systems take care of driving related tasks such as lane keeping, cruise control and collision avoidance (Karvonen & Kujala, 2014). Which could potentially

lead to behavioral adaption and skill degradation (Saffarian et al., 2012; Wahlström et al., 2011). Along with the development of autonomous and remote operation systems for container cranes, the time per task decreased, making it more task intensive. An operator must now switch focus between tasks faster than before (Karvonen et al., 2011). This is likely to happen when monitoring several ships at a time, shifting between the different ships and tasks could be overwhelming for an operator. (Wahlström et.al., 2015) It was also found that it was difficult for the crane operator to estimate distance when a conventional camera was used in place of stereo vision (Karvonen et al., 2011).

These issues must also be considered regarding comprehensive object evaluation and empathy. There is a great difference between a small sailing boat, logs of wood and pirates, regarding the navigational aspect, but also security, empathy, and communication. Additionally, the relevance of implicit intentions is also of great importance since humans might read and understand the intentions of other humans differently than an autonomous system (Wahlström et al., 2015).

2.5   Trust and blame

An operator who lacks trust in an automatic system might not be able to use it to its full potential, however, excessive trust leads to less monitoring and over reliance on the system (Hogg & Ghosh, 2016). False alarms and misses will affect trust, the extent to which trust is affected depends on the consequences of the two. To which extent a false alarm will affect trust depends on the point of time it occurs (Hoff & Bashir, 2015). A false alarm that occurs early in the interaction with the automated system will have a greater negative impact on trust, than the latter (Manzey et al., 2012). The first encounter and impression of the system's capabilities will therefore build the base of trust. Automation errors related to tasks perceived as easy will have greater impact on trust compared to tasks perceived as difficult (Hoff & Bashir, 2015). The more negative a consequence related to a false alarm will be, the more trust will lessen (Madhavan et al., 2006).

An operator who has overconfidence in the automated system will suffer from decreased monitoring performance which will result in a difficulty to detect critical deviations and act in unanticipated situations (Hogg & Ghosh, 2016) Automated-induced complacency affects both experienced and new operators, it is thereby not reduced by experience or practice according to Parasuraman and Manzey (2010).

Awad et al. (2018) studied if humans were blamed in accidents involving autonomous vehicles. When both a human and an autonomous system were driving, less blame was attributed to the autonomous system. When the autonomous system was solely in control of the driving, the blame was nevertheless partially attributed to humans, for example blaming the passengers or the producer even though the autonomous system was exclusively in control.

2.6   TNO Report

Toegepast Natuurwetenschappelijk Onderzoek (TNO), which can be translated into "Applied scientific research" is a research organization which investigated human factor issues linked to monitoring and controlling automated systems, focusing on DP systems (TNO, 2018). Highly automated autonomous systems are essentially controlling all components themselves, which means that the operator would only interfere whenever the system fails and thus does not need to constantly be aware of the system operation. However, due to the lack of situation awareness, the operator cannot interfere quickly and effectively in the case of a failure (TNO, 2018). The more reliable and robust automation that is added to a system, the more likely operators will be unaware of critical information and unable to take command if needed (Endsley, 2017). Due to the short time window where it is possible to react, while the chance of preventing an accident lessens with time, this kind of situation is prevailing during DP operations. (Chen and Moan, 2003; Sandhåland et al., 2015).

2.6.1   Intelligent Operator Support Systems

The report by TNO (2018) brings up several alternatives to encounter the socio-technical challenges that occur during DP operations. Human aware Artificial Intelligence (AI) can calculate the operator's situation awareness compared to the suitable situation awareness for a specific task. Explainable AI explains the line of thought to increase trust. By using predictive analysis, the Intelligent Operator Support System (IOSS) can show if the ship will drift the next 15 minutes. TNO (2018) mentions the term "disruptive technology", which is automation that offers support when it is not needed. This adds to the workload and impedes the operator.

TNO (2018) discuss the concept of the roaming operator, which enables a DPO to leave the DP station for other activities, such as rest or paperwork. They tested the concept by giving the DPO a tablet and a smart watch. The tablet and watch were equipped with several features, including AI technology to adjust the support and information flow to each operator.

The operators were in general positive to the concept including the technology. However, they were reluctant to leave the bridge, but were optimistic toward the opportunity of roaming the

bridge. A captain who participated in the study said that he would never let the DPO leave the bridge. There was also a reluctance to allowing the software execute anything silently. However, the DPOs stressed that when they got more trust in the system, they might lower the notification levels. The ability to check why the software came to certain predictions would increase the trust for the software since the operators can understand the line of thought (Figure 3) (TNO, 2018).
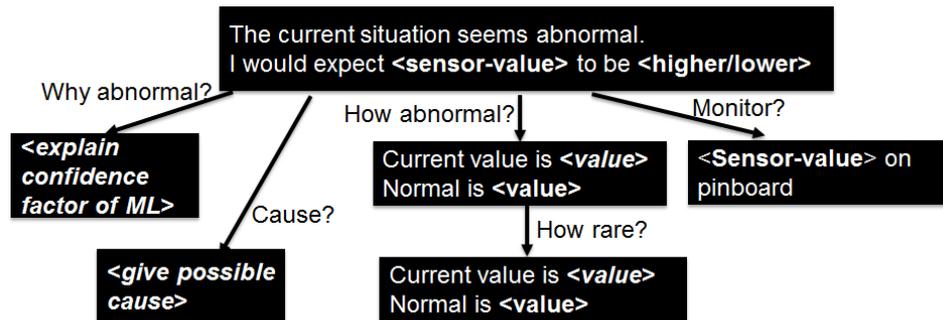
Figure 3. Dialogue tree of smart notifications (TNO, 2018, p. 35)

2.7 The impact of human-machine interaction in maritime operations

Operators will have to develop a safe level of reliance when operating an automated system (Hogg & Ghosh, 2016). Ineffective monitoring, inaccurate situation awareness and automated induced complacency are identified as typical issues in human-automation interaction (Dhami & Grabowski, 2011). The introduction of electronic navigational aids was to improve safety and situation awareness, however, there is a consensus around the fact that bridge watch-keeping has eroded, leading to groundings and collisions (Hadnett, 2008). Wickens and Hollands (2000) found out that it is 50% less likely that failures are detected when operating a high reliability system.

2.7.1 Skills

To optimize the use of socio technical systems, Lee and See (2004) suggest that the operator must have an extensive knowledge of the automatic system, including design, algorithmic processes, application, reliability and how the system is affected by a changing environment or interactions. They also recommend practicing switching between automatic and manual control. The ability to analyze and manage data will be important competency for an SCC operator of unmanned ships (Hogg and Ghosh, 2016).

2.7.2 Situation awareness

The alarm system is the most important tool in the SCC since it triggers the operator when needed and keeps the operator in the loop for further actions. Some operators understood when a situation could evolve into a critical one, which is a sign of possibly achieving a level 3 SA (Man et al. 2015). A loss of harmony negatively impacts lower levels of SA as well as higher level SA, also known as perception and the ability to foresee how the situation evolves. An operator is not in the loop as an officer on a ship would be, the alarm system should be adapted for an SCC and not on board operation. This implies that there should be sufficient time for an operator to get back into the loop and regain situation awareness to manage the situation in the same way as someone on board would. Thus, an alarm should activate earlier for an operator, on the contrary to, an officer. The alarm should also show the tendency of the situation to help the operator regain situation awareness. There could also be additional visual and audial information to engage and support the operators (Man et al. 2015). Degraded situation awareness and ineffective monitoring combined with an over-reliance on automation can lead to a startled response when an operator is facing a sudden automation failure (Jarvis et al., 2014). Endsley (1995) also points out that operators detect problems slower if their situation awareness is degraded.

2.7.3 Automation and confirmation bias

Automation bias is when automation is perceived as a powerful agent with a capability to analyze on a higher level (Lee and See, 2004). Automation bias will make an operator trust automation more in favor of other information inputs, such as their own senses (Lenton, 2015). Confirmation bias can increase the automation bias, it will make the operator look for signs that can confirm the current understanding of the situation and reject anything that speaks against it. (Pazouki et al., 2018)

2.7.4 Designing the SCC

Geiselman et al. (2013) states that the design should be focused on creating an effective cooperation between the operator and the automated system. According to Wahlström et al. (2015), when designing an SCC, the support for awareness, efficient communication, local and remote collaboration, and the feeling of presence should be considered.

2.7.5 Human performance and workload

According to Young and Stanton (2005), the performance of an individual declines when the mental activity demand exceeds the supply, however, Young et al. (2015) discovered that

mental underload and overload can interfere just as much on an operator's performance, both leading to performance decrements, errors, and distractions. Performance can also be affected by transitioning between extremes of workload (Edwards et al., 2012). Due to these reasons, it will be vital for an operator to maintain an optimal level of mental workload to safely operate autonomous vessels.
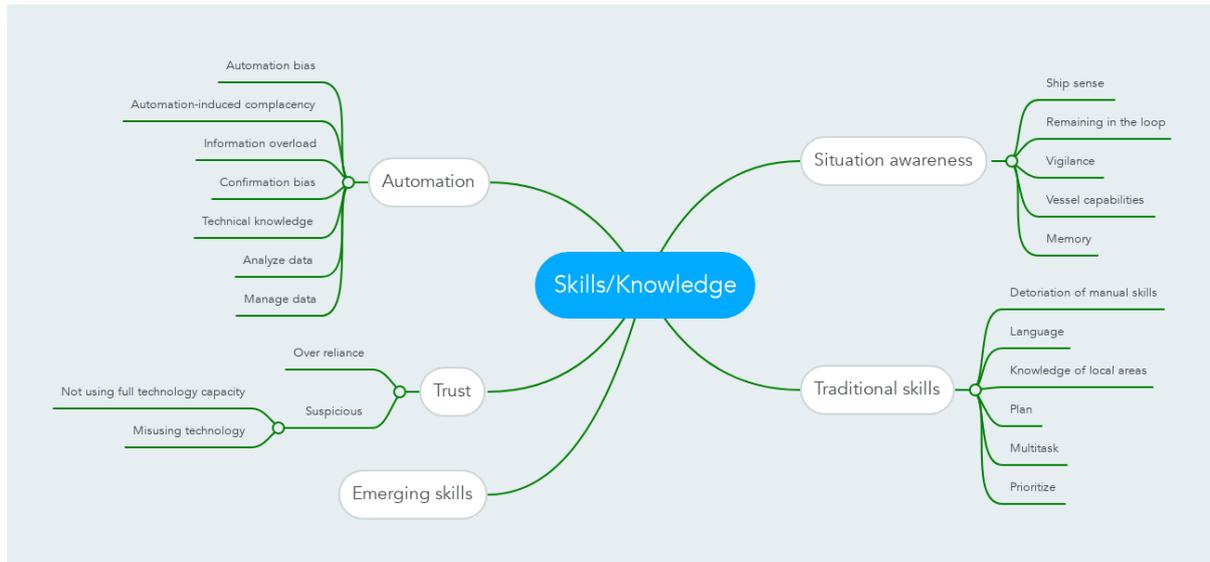
Figure 4. Skills and knowledge of a USV operator

3 Methodology

This study comprises of an ethnographic study and two sets of semi-structured interviews. The ethnographic study led to eight interviews dedicated to exploring the opportunities of using automation-based technology in offshore wind farms. An additional four interviews were conducted with actors within remote and autonomous systems.

3.1 Ethnographic study

The first step in the data collection was a descriptive ethnographic study of DPOs in their workplace. The ethnographic study was aimed at mapping out tasks performed by DPOs during DP operations in a wind farm. A goal-based task analysis was compiled based on the results from the ethnographic study (Figure 7).

3.1.1 Challenges

When conducting ethnographic participant studies issues can arise when the observer is entering the study field. These can include the observer's difficulty to earn trust, come across as obtrusive and difficulty getting accommodated in the new setting (Taylor et al., 2015). In this study, the observer had been a part of the environment for a longer period of time before the study and thereby might not have these issues. However, as the observer is engaged with the environment beforehand, it might be difficult to produce an objective observation. Ethnographic studies have high validity since they give firsthand information of a natural environment, however, the schools of methodology are not agreeing to whether an ethnographic approach is subjective or not, but it is concluded that the view of most qualitative researchers can be placed somewhere between those two extremes (Taylor et al., 2015).

Rapport is described by Taylor et al. (2015) to be the goal of every field researcher. They define rapport as "communicating a feeling of empathy for informants and having them accept it as sincere; penetrating people's "defenses against the outsider" (Argyris 1952); having people open up about their feelings about the setting and others; being seen as an okay person; breaking through the fronts (Goffman, 1959) people impose in everyday life; sharing in informants' symbolic world, their language, and their perspectives (Denzin, 1978)" (Taylor et al., 2015, p.63). The level of rapport in this study could be quite high since the observer was an existing part of the informants' work environment. The established relationship between the observer and the participants ought to have affected the study, but it is unknown how and whether it had a positive or negative outcome for the study.

3.1.2 Sample size

The sample size for the ethnographic study consisted of four individuals. This sample represented the compliment of DPOs on board the vessel at the time of the data collection.

Ethnographic study	Mean (years)	SD (years)
Age	42	12
DP experience	17	7
Wind farm experience	4	1

Figure 5. Participant demographics – Ethnographic study

3.2 Semi-structured Interviews

Semi-structured interviews should last between 30 and 90 minutes according to Jacobsen (2015). All the interviews except for one corresponded with this recommendation and lasted approximately 50 minutes each. The questionnaires can be found in the appendices (Appendix 1-4, 6). Although the knowledge of DP operations and autonomy is established, the combination is yet to be discovered. According to Malterud (2009), qualitative methods are advantageous when doing explorative research. The aim of semi-structured interviews is usually not to get a representative study, but to explore the depth of a certain issue (Mc Cracken, 1988). To enable the interviewees to expand their answers in whichever direction they find necessary, a semi-structured interview format was used for all the interviews. The interviewees have experience and thoughts that might not be discovered unless a semi-structured format is used.

The interviews were held in English or Norwegian depending on the native language and preference of the interviewees. Piekkari and Welsh (2006) did a study on the topic of using different languages during research in business. Their study showed that using different languages could threaten response accuracy while using our mother tongue can increase response authenticity. The freedom to choose between English and Norwegian will enable the interviewee to express themselves through whichever language that is the most comfortable for them. A lack of language proficiency might inhibit an interviewee's ability to express themselves. This will weigh heavier than the interviewer's lack of language proficiency and the response accuracy lost in translation.

The interviews were conducted using a video calling application or held over the telephone, depending on what suited the interviewees. Trust can be difficult to obtain when interviews are held over the phone, unlike interviews held face to face. (Jacobsen, 2015) This might have affected the validity negatively.

Jacobsen (2015) points out that similar independent interpretation and experiences on the same material from different sources increases the validity of the material. Consequently, it was important to interview all interviewees separately and instruct them to avoid sharing their thoughts and beliefs between one another before all interviews were finished.

3.2.1 Interviews with actors within autonomous and remote systems

Due to the course of the study and the interviewees' different specific experience and knowledge, the questions were tailored for each single occasion to get more relevant and significant information. By altering the questions between each occasion, the opportunity to quantify the results were limited, and thereby it was difficult to increase validity. On the contrary, requesting answers from an interviewee outside of their area of expertise is neither increasing validity.

3.2.1.1 Sample size and interviewee selection

The interviewees were selected to cover the research areas of this thesis: dynamic positioning, remote and autonomous handling. The sample size was selected based on coverage. The first interviewee was a researcher on human factors within the maritime sector. The second interviewee was a developer involved in autonomous logistic and technical solutions. The third interviewee had a background as a navigator and was working with remote operations of Remotely Operated Vehicles (ROVs). The fourth interviewee also has a background as a navigator and is working within automation and autonomy. The three interviewees working within autonomous and remote operations will hereby be referred to as developers.

3.2.2 Interviews with DPOs

The Survey (Appendix 5) was aimed to help the DPOs to prepare for the upcoming interview. The interviewees had the opportunity to add or remove categories and subcategories to the goal-based task analysis. When the interviewees were satisfied with the goal-based task analysis, they were asked to allocate the tasks to whichever category of autonomy in the matrix that they believed was applicable. During the interview, they were asked to explain how they rationalized the allocations of tasks within a level of automation framework. The revised goal-based task analysis (Figure 8) resulting from the interviews is presented in the results section. Since the interviewees are not expected to be updated on the advancement in the field of maritime autonomy, they were asked to disregard restraints due to technological, economical, or legal issues. Additionally, they were asked to reflect upon the problems that can occur when

substituting humans with technology in relation to the tasks. They were also requested to answer if these tasks could be executed by an SCC.

One test interview was performed prior to the interviews to verify the quality of the interview material. The test interview was aimed at being as similar to the upcoming interviews as possible and therefore done together with a DPO with relevant experience using a video call application.

3.2.2.1 Sample size and interviewee selection

The interviewees had to fulfil certain criteria, they needed to have at least six months experience working as DPOs on SOVs within offshore wind farms and be holders of the DPO certificate. The desired number of interviewees was set from five to ten participants. The interviewees were all working for the same company.

The age, position and years of experience were identified as factors that might affect the answers of the interviewees. The age most likely reflects the individual's overall experience, while experience as a DPO likely correlates with DP knowledge. A senior DPO who is in charge of the DP watch has different responsibilities contrary to a DPO, therefore it is reasonable to assume that the two roles focus on different things during the DP operation and might therefore come with different inputs. To get a broad set of answers, the interviewees were desired to cover as much variance in these groups as possible.

Interviews with DPOs	Mean (years)	SD (years)
Age	38	6
DP experience	12	6
Wind farm experience	4	2

Figure 6. Participant demographics - Semi-structured interview with DPOs

3.2.3 Analysis

Thematic analysis is used to identify patterns relevant for a research question (Braun & Clarke, 2006). A thematic analysis was used to analyze the interviews. The themes were equivalent to the goal-based tasks identified during the ethnographic study. Parts of the data collected through the semi-structured interviews were not applicable to any of the goal-based tasks. However, the interviewees were requested to add categories and subcategories to the goal-based task analysis when deemed necessary (Figure 8) and identified themes that did not fall into any of the categories were still included in the results section. The themes were not limited

to goal-based tasks, all other patterns or relevant pieces of information are included in the results section.

A thematic criterion is often more useful when doing qualitative research (Schreier, 2014). The datasets were analyzed and divided primarily depending on theme and divided within the theme depending on the source as recommended by Schreier (2014). If an interviewee expressed the same opinion more than once, this would only count as one person's opinion, due to the utilization of source division.

3.3   Ethics

Before participating in the ethnographic study and interviews, all interviewees were asked to read and sign the consent forms (Appendix 7 and 8). The interviews were transcribed, but due to the risk of identifying the interviewees, the transcriptions will not be included in this thesis.

The Hawthorne effect (Landsberger, 1958) is when a person alters their behavior because they know that they are being observed. Even though the interviewees are unidentifiable, they might be affected by the Hawthorne effect. The ethnographic study was conducted on a ship's bridge. This specific bridge was equipped with a voyage data recorder that collects and saves audio and software recordings. Information from the DP system on board is saved on a separate hard drive. All interviewees were already aware of their actions being monitored and saved by multiple systems. The Hawthorne effect is always present on the bridge, regardless of the study.

The specific tasks observed during the ethnographic study were generic and not categorized per interviewee. The general tasks during a DP operation are in compliance with conventions and guidelines and should consequently be applicable for any vessel involved in a similar DP operation.

3.3.1   Storage and destruction

All signed consent forms, taped interviews, and other raw data have been stored on a separate password protected hard drive. The taped interviews were deleted once transcribed. The consent forms will be stored for at least 3 years after the submission of this thesis.

A key system was used to connect the raw material to each interviewee. The surveys and transcriptions were marked with a number which was used to identify the participant but denominalising personal participant information. The key which links each identification number to an interviewee was stored on the password protected hard drive to protect the identity of the interviewees. The key is to be disposed upon finalizing this thesis.

4 Results

In this section the findings from the ethnographic study and interviews will be presented and analyzed. The interviews with the DPOs will be thematically analyzed as one data set. The interviews with the researcher and developers will be presented separately.

4.1 Ethnographic study

The DPOs were observed during DP operations within a wind farm. All noted tasks conducted by the participants during the operation made up subcategories. The subcategories related to each other made up suitable categories. A mind map was made to demonstrate the result of the ethnographic study (Figure 7). Figure 8 depicts the revised goal-based task analysis, resulting from the interviews with the DPOs. Only two categories were added by the DPOs: 'Social interaction' and 'Waiting on weather'.
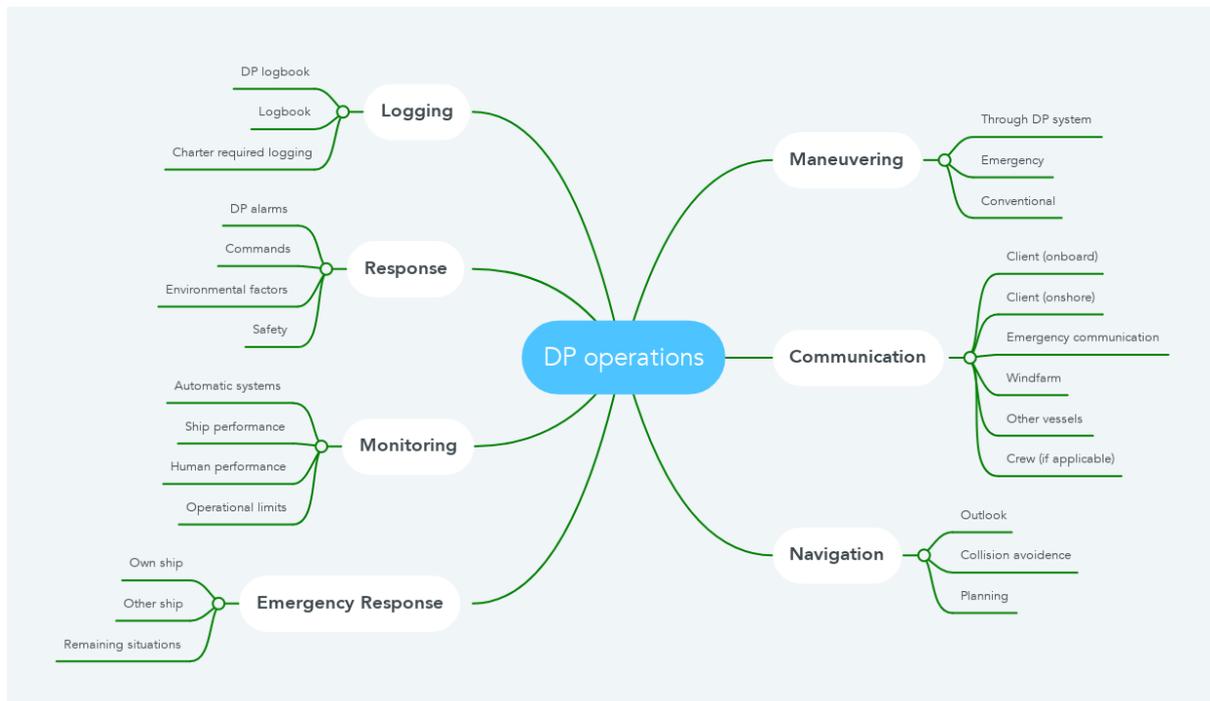
Figure 7. DP operations goal-based task analysis

4.2 Interviews with dynamic positioning operators

A total number of eight DPOs participated, however, the material from one of the interviews was removed due to insufficient engagement and answers, thereby the data collection is based on seven interviewees only. The interviewees were requested to elaborate upon their general thoughts and attitudes towards autonomous and remotely controlled SOVs in offshore wind farms.

4.2.1 Autonomous SOVs

None of the interviewees saw a challenge reducing the number of DPOs on board once it has been proven safe allocating some of the tasks to another party than a DPO. However, the interviewees repeatedly argued that the entire crew cannot be removed when having clients on board, they also questioned if the clients would even accept a vessel without navigators.

They also stressed the constant and unforeseeable changes during a DP operation. Operators of autonomous systems might become numb and have difficulties making the correct decisions when operating a highly autonomous system.

"What will also be a problem is when you have a DPO who is there to monitor 12 hours per day without taking a single decision. It is just expected that he will engage whenever something goes wrong. The risk is that he can become numb. When something happens, he is

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sitting there and would not register what is about to happen or cannot make decisions or do the right things when it is necessary. That is probably the biggest problem when a human is going to work using an autonomous system, humans have weaknesses, the better the autonomous system is, the less weaknesses that combination has, I suppose."

Another interviewee expressed similar concerns regarding the degeneration of skills.

"(…) if they are going to sit there and try to follow what an autonomous vessel is doing, and in some kind of magical way jump in and take control of the vessel. (…) Day by day, year by year they will become less capable of handling a vessel well. Or they need an incredibly good regime where they have continuous training, for example taking a part of the operations manually as much as possible, to make sure they have 100 percent control."

One interviewee explained that they operate the vessel manually on DP auto mode to keep the operational limits up. The DP would not be able to work in the same wave height without the compensation from the DPO.

"The DPOs sitting upstairs they know what they need to watch out for, you adjust the DP manually for it to work in auto."

The interviewees were somewhat misaligned regarding the abilities of an operator and an autonomous system, respectively. Some interviewees mistrusted the abilities of autonomous systems, while others focused on the incapability of operators.

"The autonomous systems are becoming better and better and the largest weakness is often the humans that are supposed to operate it. If you have the world's best autonomous system and there sits an idiot who tries to fix whatever the autonomous system cannot perform, then it will go bad anyways."

Two of the participants also talked about possible weaknesses on the programming side of autonomous technology.

"I get the feeling that the developers that want to replace us with autonomy does not have competence on what we are actually doing. You hear the way they are thinking, that you might meet, that does not know a lot about ships. They can ask really strange questions. For example, a father of a friend, he asked if it is not easier to just turn off the ship's engine instead of using DP if you want the ship to keep position. Many people think like that, and my impression is that the people who are developing these systems might not focus on the same

problems as us, who knows a lot about operating a vessel. Another thing is that there are so many thousands of factors that you would need to capture, I highly doubt that the programmers can do that, or that it takes a long time."

"The DP is not smarter than smart, not smarter than what it is programmed to be."

Two of the interviewees specifically mentioned gut feeling as a valuable asset an autonomous system might lack. They also mentioned experience, thinking outside the box, knowing what works and not and how to interpret information coming your way as valuable.

"To catch the signals that might come in your way, intuition, and gut feeling. Maybe when it comes to understanding when people are in distress, or understanding a radio message, or when something is out of the ordinary. When speaking to people, listening to the tone and what they are trying to say. Maybe not word by word, but the underlying message."

4.2.2 Remotely operated SOVs

Some issues of remote operations include reduced situation awareness, lacking emphatical connection with clients and crew remaining on board, and communication challenges. Conducting maintenance and emergency preparedness were brought forward as additional complications. Many of the interviewees pointed out that it might be too complicated to program for every possible outcome. Different skills might be required by a DPO onboard contrary to an operator ashore. One interviewee focused on the degeneration amongst the remaining operators and how that increases risk of humans remaining on board.

"I would not have wanted any type of remote steering during operations where you have human lives at risk. (...) I personally think that it will degrade the knowledge of the person who has to intervene if he is too disconnected. If you have to have a person who needs to be 100% ready to jump in and has to be alert on all of the possible situations that can emerge, I think you will get a very bad intervention compared to how it is per today."

"Autonomy itself, I rate lower than remote operation. I think there is more potential in the remote operation part, that they can relieve the operators and have a shift system, of 8 hour shifts ashore to supervise standby time and things like that. An autonomous ship in a wind farm, getting people on and off turbines, I struggle to consider safe. You can program for many eventualities, but will it manage to see those three waves we have to wait for? I don't think so."

One of the interviewees mentioned that a standby team ashore can keep track of the vessel during less risky operations, for example, activities such as stand by and transit, while the vessel's crew is doing other things, such as maintenance.

4.2.3   Logging

In general, the interviewees considered logging as an activity that can be done autonomously. As per today, there might be as many as three logs to fill out: bridge logbook, DP logbook and charterer's log. Autonomous logging and system networking were perceived as positive additional features potentially relieving one member of the bridge team, with little alterations to current systems. Three of the interviewees stated that automatic logging already exists in addition to the current logs.

However, two interviewees problematized autonomous logging. The bridge logbook is a legal document, something written in the logbook is irrevocable and can be traced back to the author. The interviewees questioned whether an autonomous log can be trusted to work as intended. One of the interviewees experienced the difference between automatic logging and logging by hand a couple of years ago.

"... it's like the case we had a couple of years ago when it was logged electronically that someone pressed "take-take" on a station, causing a critical situation. The officer who was by that station said he did not press "take-take". According to the police who investigated the case, it was logged electronically that someone pressed it, but since the officer did not plead guilty, they could not charge him for it. But if he would have written it in the logbook, it would have been considered a "fact". A logbook is not the same as a log."

None of the interviewees mentioned remote allocation as a practical option.

4.2.4   Response

The interviewees pointed out that response can be handled by an autonomous system, but to a varying degree should be approved by an operator either ashore or on board. It was argued that daily tasks and less complicated situations could be suitable for autonomous response. None considered the possibility of a fully autonomous response. Issues regarding autonomous response were the number and nature of factors a system must be able to consider when taking a decision, as well as the ability to draw logical conclusions. One of the interviewees pointed out that an autonomous system will not be as good as a skilled DPO, decisions based on

experience might be better than those based on data. However, an autonomous system will be able to process more data.

Four of the interviewees specifically mentioned that someone must be on board due to reasons such as lack of kinesthetic feedback, connection delay, limited response time, and camera coverage.

"I think you are just too close, that it will never be safe doing it remotely. You might have half a second to do something. Since we are only 10 meters from the installation, you have minimal distance between a safe operation and a catastrophe. You also have one contact point, the gangway, and you can imagine all the scenarios of an automatic disconnection. A human can override and hold it half a second longer if someone just passed over. There, the main focus should be on the human."

A change in sensor input can be caused by a factor that an autonomous system might not have the ability to comprehend. It was also mentioned that a system might be a better alternative when working within the operational limits, while a human might be a better alternative whenever working outside of the limits.

4.2.5 Monitoring

It was generally considered that autonomy could take on a greater role in monitoring the DP operation, except for one interviewee that placed monitoring on the decision support autonomous level. However, the interviewee later stated that it would be fun to see a system with artificial intelligence rather than just a Kalman filter, which is used by DP systems today. The Kalman filter needs time to get used to new forces, for example the current, that could be improved for better autonomous systems by updating the model faster.

Human lives at risk and difficulties when the vessel is operating outside limits were two of the reasons why fully autonomous monitoring cannot be accepted. However, two of the interviewees said autonomous monitoring would reduce the workload for the DPO, by managing alarms and filtering out unnecessary information. The acceptable level of monitoring by an autonomous system will be dependent on how well we can trust that system when human lives are at stake. An example that was brought up by two of the interviewees was the issue of monitoring nacelle position. Normally, when a vessel moves close to a turbine, the nacelle must be locked in a certain position to avoid the blades of the turbine and the vessel colliding with one another. The position of the nacelle is usually adjusted and confirmed by a control center.

"Verification of nacelle position, they have still not managed to get that right, we still have to go and look visually."

Human monitoring could be fulfilled by having some kind of tracking function of an operator's attention, equivalent to the verification of hands on the steering wheel for autonomous cars. The longer an autonomous system is working flawlessly, the more an operator would relax.

"The more comfortable you are with a system, the more you relax until you get an incident, where you will pay more attention, for a short period of time, until you have repressed it."

Kinesthetic feedback and delays due to internet connection were mentioned as factors making remote monitoring difficult. One interviewee pointed out that it might be better to monitor from ashore due to less distractions.

"I also see that when we are sitting on the bridge, there are a lot of distractions, people coming up to have a chat. Maybe it would have been better to have one sit ashore and another one on the bridge."

4.2.6 Emergency response

Emergency response was the category on the task analysis that was rated as the least likely to be handled by an autonomous system or remotely. The main reason was the need for physical persons to handle an emergency, whether it is a fire, man overboard or evacuation, especially with clients on board. The uncertainty factor was brought up as an argument to why humans are considered necessary on board.

"(…) when it's emergency response, you don't know what the emergency is going to be. So, to create an autonomous system that can be able to deal with any thinkable drama is pretty impressive, if someone was able to do that."

Some of the issues regarding autonomous handling of emergency response includes how to identify an emergency, the amount of people it takes to respond to an emergency effectively and maintenance of emergency equipment. One of the interviewees gave an example of a firefighting system that did not work as expected.

"On my vessel it is almost impossible for a fire to start because we have water mist nozzles. (…) now we just had a service guy on board and many of them actually did not work. Then you need a back-up anyway. That backup for us is the crew."

One of the interviewees was quite positive, saying it is possible to preprogram emergency responses. A DPO on board or ashore might be needed to decide how to proceed and investigate. However, an autonomous system's ability to think outside the box could cause complications.

The interviewees especially agreed on the issues that might occur when moving parts of the emergency respond teams ashore, however they also stated that there is a manning requirement that is supposed to maintain safe manning. One interviewee stated that he doubts that the manning requirement would be altered due to autonomy. Two of the interviewees proposed to use other resources on board, for example the clients or galley staff. One of the interviewees reflected over how an emergency might be affected when taking unmanned vessels into use, during a man overboard incident.

"(…) but then the FRB gets to the casualty and they're unconscious. How are you going to recover them? (…) again, time lost, and possibly the person dies."

Situation awareness during remote emergency response was not perceived as a problem to one of the interviewees but depends on the level of communication and a good information foundation. The interviewee also told a story of how important it can be to have people on board to follow up incidents.

"We had a situation where we got a water leakage on one of the engines, at first it was only that engine. But afterwards it was shown that the water had been flushing directly onto a cabinet, it was the electrician that noticed it. It was just because he was attentive, and we might have lost the engine that was remaining. Certain situations have the possibility to evolve into something worse."

Two of the interviewees questioned how good of a situation awareness the DPOs can possibly have when everything is autonomous.

"Everything is autonomous, they are sitting there drinking coffee and thinking about what is going on at home. Suddenly everything is red, and you have 265 alarms on the screen. That is the hindside of giving the command to an autonomous system, when you throw in the towel you are probably served with a list of things that you need to figure out."

"The situation awareness will be affected by that. If you are going to sit and watch, 99.99 percent of the times everything will be as planned. And you have a very small fraction of situations where you will have to take over manually. How much manual time will an

operator get in a year? And how suitable is that person to take control in that situation? He can fast be traumatized by the whole situation."

A system must be able to differentiate between a false alarm and a real alarm. One interviewee mentioned that a fire should always be verified. Taking a shower or getting out of the sauna might be identified as a fire by a system.

One of the interviewees also mentioned experiencing sabotage from clients and pointed this out as a possible safety risk when moving crewmembers ashore. You never know which kind of people you get on board and what their objectives might be.

4.2.7 Maneuvering

Maneuvering was perceived as an activity that could be done autonomously or remotely to a certain degree. Transiting between turbines, and to and from the wind farm was pointed out as more likely to be done by an autonomous system or remotely, while maneuvering close to installations was considered riskier, thereby requiring a DPO. Four of the DPOs believed that the operational limits would be narrower using an autonomous system, at least in the start phase. A solid set of operational limits was however perceived as a positive contribution. Today the operational limits can be overridden by the senior DPO, which means that the senior DPO is subject to persuasion campaigns. The DPO will be blamed if the vessel is not operational as promised according to contract but is also responsible whenever something happens, especially working outside set operational limits.

"I think we are sometimes quitting too early, and sometimes working when we should not. An autonomous system might be able to take more factors and data into account than a human is. An autonomous system might take better decisions. Maybe it won't work longer, but it will take more safe decisions."

There was no consensus if an autonomous system could maneuver better than humans. A computer will be able to analyze larger data quantities, thereby it is not certain that it would draw the same conclusions as a human. Sudden changes in weather were brought up by several of the interviewees as an example of what an autonomous system might be less likely to handle well. An autonomous system would be dependent on information input from, for example, weather buoys. The question is if an autonomous vessel can be prepared for an event that cannot be foreseen.

"A good operator will give a red light when he feels the vessel move up, even if we are in position. But he knows that in 20 seconds we are not in position anymore."

"I've never seen weather like it, the wind hit 80 knots. (...) just like a click of your fingers. And then we had horrendous hail. And then obviously the ship couldn't keep its heading because we just had the head locked on. And we had fore and aft locked in but not sideways. So, all the alarms would go in and because we've drifted out of our parameters, the DP started trying really hard to get back into its setpoint parameters. And because it was trying too hard, the engine that was on was getting overloaded. In the meantime, the second engine was trying to come on, but it wasn't coming on in time."

The importance of redundancy in the form of human experience and knowledge was highlighted by one of the interviewees.

"... we have spoken way too little about the primary redundance. We are absolutely drowning in all the possibilities we have with technology. You forget that the largest redundancy also needs knowledge. That is undermined by all the people working with autonomy, the more an officer can sit and poke his nose and look out the window, the worse he will be at handling the vessel when the autonomy fails. If you want to cross the finishing line regarding autonomy and autonomous systems, you have to invest equal amount into manual knowledge and ship handling."

"The last barrier will be the programmer instead of the operator in a fully autonomous ship."

Kinesthetic feedback was mentioned by two of the interviewees and communication was again brought up as one of the difficulties of conducting remote maneuvering. Camera positioning would be vital and might even give a better overview than what the officer has at the maneuvering station today, for example when going through a lock.

One of the interviewees mentioned a function called "docking mode", which allows the vessel to move from the safety zone border to the gangway connection point. However, as per today the function does not take weather or fuel efficiency into account, including whether the vessel is drift on or drift off. The interviewee stated that the docking mode takes three times longer to move to the connection point, compared to an operator.

One of the interviewees did not consider maneuvering close to installations as an activity requiring humans but did highlight that humans should be available to take over control if required.

An operator should decide what to do in an emergency maneuver, including overriding a system and taking the final decision. One interviewee stressed how important continuous maneuvering training is for situation awareness. The DPO will have a better feeling of what the ship is affected by and is struggling with.

"... if the vessel is doing everything, I suppose it is easy to become complacent, because things are being sorted without intervention. I suppose it is always like that when you give humans a monotone task."

4.2.8 Communication

Some parts of communication were considered easily transferred to an autonomous system, this includes communication of the daily plan, approval from the control center of the wind farm and other monotone and frequent tasks. Emergency communication and communication with clients were stated as being less likely feasible by an autonomous system.

"Communication is easiest to do between people."

One interviewee pointed out that the clients cannot be made responsible for the requests that they might have in areas where they lack knowledge, a DPO must decide what is reasonable and be responsible for the execution. Execution of clients' requests can imply more complicated emergency handling, due to longer distances between turbine locations or decreased navigational safety due to turned off radars. An autonomous response to the daily plan would transfer responsibility from the bridge crew to the clients. They can be supplied with arrival times based on the locations they have selected. However, another interviewee said that these requests could very likely be handled by an autonomous system, without being approved by an operator.

"They are dependent on being able to talk to whomever is steering the vessel. What always happens is that we get changes to the original plan. Someone forgot something, you have to pick someone up, you have to be somewhere at a certain time. There might be certain situations where the client is requesting specific details, like heading. We probably need an operator on board or on shore who can fulfill those requests. I have a difficult time to imagine that an autonomous system will be able to transfer that request into practice."

It was questioned whether an autonomous system can understand a panicking human, or if a human would even want to communicate with a system during an emergency. It was concluded that we need the human element in emergency communications.

One of the interviewees said it can sometimes be difficult to explain things to someone who is not on site. A DPO and an engineer ashore can relieve the vessels crew by handling the communication from ashore. Remote control of the ship might enable more seamless communication since the engineer, crane operator, gangway operator and DPO can be placed in the same room. The magnitude and meaning of alarms can be communicated directly between the parties and they will hear each other's alarms.

When placing one operator ashore, communication becomes even more essential. Verbal communication will only be problematic from the start, making it even more important that it is someone who communicated well already before being moved ashore. Bridge resource management would get even more complicated.

4.2.9 Navigation

The interviewees were generally positive to autonomous or remote navigation. Collision avoidance, planning and keeping outlook were considered tasks that could be handled autonomously. However, there's a need for verifying the actions of the autonomous system.

One issue that was mentioned by two of the interviewees is how an autonomous system or remote operator could identify objects on the radar, for example fishing gear. Remote operation would again require good camera coverage and quality. Another of the interviewees said that it will be safer to give away the command to emerging technology.

One of the interviewees inferred that an outlook can be replaced with an autonomous system, however, it is dependent on the alternative. An autonomous outlook will always be better than an outlook sitting in front of their cellphone.

According to COLREG rule no. 21 (COLREG, 1972) a vessel's stern light starts where the sidelight ends and vice versa. This means that at two angles, the vessel obliged to 'give way' can rapidly be altered. This issue was mentioned by one interviewee as something that could be difficult to consider, one second the vessel should give way and the next it is the other vessel that should give way. The interviewee also exemplified how difficult communication can be between vessels on collision course.

"To me it seems difficult to have autonomous collision avoidance (...) There are a lot of strange people in this world. I hear it all the time on the VHF, none of them wants to give way for the other one and they start arguing."

It was specifically stated by one of the interviewees that passage planning can be done by a system, but that it should be verified for logical flaws by a human.

4.2.10 Human factors

One interviewee mentioned the importance of having senior management on board to handle conflicts between crew members. Two interviewees pointed out that the remaining crew might be affected by not having the same social interaction as before. One interviewee questioned how many crewmembers can be removed before the standard of food, hygiene and emergency preparedness suffers.

"How do you get someone to thrive if you take it too far? Too many machines, little time at home and a lot of time at work. That might be something to consider as well, how long can a human be satisfied with their job when they are alone and address only a computer or a voice of a person who you have never seen the face of."

Two of the interviewees questioned whether a person ashore the same level of sympathy and sense of responsibility for those remaining on board.

"If something goes wrong, the person ashore can get an attorney to write some beneficial clauses, protecting themselves long before anything has happened. If you sit on the bridge, you see what is happening, it is right in front of you, I am sure you will have a different sense of responsibility than someone who is sitting and caring more about the stock price. They will not register the same things as someone on board, they don't feel the wind, the vibrations and they won't be as caring for their friends or colleagues who are on board. We are believing so much in the accuracy, that we forget how dangerous it can be."

4.2.11 Unmanned bridge

Some of the DPOs did not see it as appropriate to leave the bridge completely, while others did see it as a possibility if the autonomous system or remote steering proved to be good enough. Concerns were raised regarding who would be responsible and how to regain situation awareness if needed. About half of the interviewees still stressed the need for having someone on the bridge to monitor high-risk operations, such as gangway connections and to monitor situations which are out of the ordinary. About half of them stated that if they trust a system

working perfectly, they would feel more comfortable leaving the bridge, but that is something that requires the system working flawlessly for a long period of time, building trust.

4.2.12 Human technology interface issues

One interviewee pointed out that we will need competent operators, who are adapting along with the commencement of the autonomous technology. Two of the navigators pointed out that DP systems today are not user friendly. One of them stated that they had been complaining for years, but the system has still not improved.

"... for example, when you get an alarm, you must enter the manual to understand what it is even trying to tell you, in a way. There are many operators that do not understand those alarms or manage to remember what they mean. The one's that have experience can often find what the problem might be, but when new people come here, I remember myself the first time I sat in the DP chair. I did not know what anything was."

The fact that the operators today experience manual handling, which might not be the case in twenty years' time, was also considered a future issue. The operators in twenty years will only know how to operate an autonomous system and might lack the knowledge and experience to handle the vessel conventionally.

"I think a lot of the competence disappears. Well, that they are not taught to drive manually [cadets]. But the question is if they need to be trained in that if the systems are so good that we can trust them eventually. Then you will need another type of competence, you need the competence to operate, or look at a system working."

Another of the interviewees explained the need of filtering out suitable autonomous operators.

"We have had people on board that I would suspect could never learn this, being a DPO in a wind farm. Not managing to focus, classical example of someone who will never learn this. On an autonomous ship here, you would need a good understanding of the system and situation, I think you will have to filter out those who will be suitable. You cannot say they should take an extra module at school, I actually think they need to go through some kind of practical filtering."

4.2.13 Weather waiting

One of the DPOs mentioned that weather waiting, stand-by due to weather, can be a challenge on an autonomous vessel. It is argued that a human on board will feel, again coming back to kinesthetic feedback, which movements that are best for the vessel and people on board. The

interviewee pointed out that the same problems involving kinesthetic feedback will apply for transiting.

4.2.14 Economic, legal, and technical factors

Economic, legal, and technical factors were not to be considered in this thesis, but it was confirmed by the interviewees that economical, legislative, and technological progress will be a prerequisite for autonomous and remote operations of SOVs.

Some of the interviewees questioned who is to be responsible for the safety of the vessel and people on board when the operator is expected to perform other tasks, while relieved by an autonomous system. One of the interviewees also pointed out that the use of autonomous systems might not be dependent on what is practical or economical, but on what is legal. Whenever it is legal to allocate a task to an SCC or an autonomous system, the companies will be forced to do so due to competition. It will be equivalent to the transition made by steam vessels to diesel vessels. Initially, it will be expensive, but it will eventually make out the difference between the companies that manage to survive or not. The economic incentive was pointed out as an important factor by many of the interviewees. A vessel that can operate without any people on board implies a greater economic incentive for autonomous or remote operation, because it is possible to remove the whole accommodation area. However, an SOV in an offshore wind farm is dependent on the clients on board, limiting the economic incentive.

"The difference between what is practically possible and effective, that is one thing that is quite important. That's what I mean, that today, we have the technology to do all of this, but for someone building ships or clients hiring the ships it would not make sense to have a fully autonomous ship within the wind farm industry."

4.3 Interviews with actors within autonomous and remote systems

In this section the results from the interviews with the researcher and the developers within autonomous and remote systems will be presented.

4.3.1 Interview with researcher

A system does not need to be supplied with a lot of intelligence to understand a simple situation. A more complex situation requires experience from the operator and an intelligent system. The operator must have a comprehension of the situation and must judge whether the system can deal with such a situation. Hence, the ship requires help from the operator along with increased situation complexity. An automated ship system's capability of handling a situation is not

necessarily answered as a yes or no question, it is more like a gray area and rather depends on the situation, the sophistication of the software and abilities of the vessel.

Desdemona (Desdemona), a moving simulator, was used to test if a captain would make decisions based on the movement of the vessel. When the simulator was not simulating the movements of the vessel, the captain commenced with full speed. When the motion was activated and the captain could feel the movement of the ship, he reduced the speed because he felt that the ship was unable to cope with the forces.

Switching between vessels in different regions, weather conditions and situations can be very demanding and costly for an operator. It is difficult to say how many ships one operator could handle at once. It is problematic when an operator is lacking situation awareness while a critical situation arises. An operator cannot be expected to keep situation awareness for six-seven vessels at a time.

The solution is not necessarily to maintain a high situation awareness, people are not good at keeping up situation awareness, but to develop a system that helps you gain situation awareness when required. Adaptive technology can be used to monitor and analyze behavior to evaluate the level of situation awareness of an operator.

The interviewee talked about the first lethal crash with a tesla. Due to several unlikely factors the technology did not detect a truck in front of the tesla and collided with it. It is challenging to judge how long one can wait for the system to act, not only if, but when to act.

4.3.2 Interview with autonomous logistics developer

The interviewee argued that the goal is not remote steering, but autonomous steering with an SCC holding a monitoring role with an exception handling function. He argued that it is because the premium set by the insurance companies goes up on remote steering compared to autonomous steering. The SCC will be used for exception handling and planning. The interviewee believes that the industry is complicating the situation, multiple redundancies is not something to focus on, rather the focus should be on maintaining the current level.

The motivation for deploying autonomous vessels is to reduce cost, reduce environmental impact, and increase safety. The interviewee argues that autonomous steering will reduce accidents at sea, contribute to a better work environment, and health benefits because employees will not have to work shifts.

Connection latency was pointed out as an issue conducting remote exception handling. The interviewee argued that the SCC design must enable good human-machine interaction. Information could be presented with different lights, signalizing status. Limiting information overflow, simplifying, and merging products are methods to be used when designing an SCC. The interviewee pointed out that things should be simpler to engage in, for example when renting a leisure boat, everyone should be able to operate it. An IKEA manual was brought up as an example of a successful attempt to make an understandable instruction manual.

"(…) they are best in the world on presenting something visually that you understand without the… you know, the disclaimers in ten different languages, you throw them away and you take out the booklet and it might be ninety-seven percent of the population that at least have touched a hammer and screwdriver, they are able to assemble an IKEA unit."

An operator at a shore control center should be a qualified sailor, at least for now. However, the interviewee does make a comparison to drone pilots and fighter pilots. The best drone pilots are gamers, and not trained fighter pilots. Fighter pilots have barriers, for example taking G-forces into account. Drone pilots do not consider human factors, for them it is a computer game, they push the limits. It was concluded that he believes that it is different for ships, a captain in an SCC must have experience as a master from real vessels. Additionally, some kind of education within information technology is necessary. The ability to multitask and communicate was mentioned as necessary operator skills by the interviewee.

4.3.3 Interview with remote ROV developer

The interviewee mentioned that there is no legal requirement to be two DPOs during DP operations but an established practice. Consequently, the possibility of removing one DPO from the vessel is so established that no one is willing to look into it.

4.3.3.1 Remote ROV operations

One of the challenges moving a ROV pilot from a vessel to an SCC was the interrelationship between the ROV pilots. On board a vessel, the pilots are sitting next to each other, they hear what the other pilot is doing and saying and see each other's body language. This was solved by installing a video wall in the SCC and on board, enabling the ROV pilots to see each other in real time. The ROV pilots explained the following when moving from on board to on shore operation.

"(…) today we have 100 milliseconds latency from the camera to the ROV control room on board, we add 40-60 milliseconds, thereby we have a bit more delay, not a lot, but they say that it is kind of like borrowing the neighbor's car, a bit different in the beginning and after a while you get used to it."

The benefit of moving ROV pilots ashore is the need for less pilots per ROV, which in turn reduces cost, man-hours on board, HSE statistics, and CO_2 pollution. The interviewee mentioned the social aspect, that people who usually cannot work offshore, due to for example medical reasons or family related reasons, can actually continue their career as ROV pilots in the SCC.

4.3.3.2 Remotely operated SOVs

Sufficient and stable internet connection is a limiting factor which is not available to the required degree to conduct DP operations from ashore at this point in time. Safe manning will be required but moving people ashore will make out a safer workplace.

It has been tested to move crane operators from the crane to the bridge, there they are operating using cameras, but are also able to view out the window. The interviewee mentioned that the view would be lost by moving ashore but that it would not be a great transition when already operating based on cameras. Sensory impressions can be compensated for by supplying relevant information. Operating a crane using cameras worked well once the operators got used to it.

The interviewee mentioned that a future SCC operator needs a certain technical understanding. The operator must be supplied with information in a good way using integrated systems.

The interviewee mentioned that systems on board a typical offshore vessel does not always work as intended, because the products are not yet finished by the suppliers.

"You must juggle to get the ship to operate the way it should. I am thinking about everything from automatic data from motors, fuel saving, different load on switchboards, joysticks that you go in and out of port with, autopilots, there are very many things that are not good on a vessel."

The interviewee points out that in the short run they are not focusing on removing both DPOs from the vessel. He is pointing out that there is a reason for doubting autonomous vessels exemplifying the development of DP.

"The most autonomous systems that we know of is the DP system (…). They have tried to get that computer to steer the ship for over 40 years, you have big actors that have used huge resources to get the DP system to be autonomous, but it is shown, over and over again, that it is not watertight. Many times, it can be systems that are subordinate to the DP system, for example, on the machine and Power Management System (PMS) side, or a hocus pocus system built by an electrician on a shipyard, with cross connections and different things."

The interviewee argues that remote development is built on "seeing is believing", you try a set up, you see if it works, and you develop it from there.

A good operator maneuvers the vessel with the external forces instead of against them. That might be hard to learn for an operator that has never worked on board but might be solved by a graphical display presenting when too much force or fuel is used.

The interviewee argued that the initial limits would be narrower when operating vessels from ashore. Seamanship will be replaced with good sensors and information technology. By having a *trial* and *error* period, the operational limits will be found.

The interviewee has experienced that some of the actors working with remote operations have the impression that everything can be solved by writing a new code or by obtaining a reliable internet connection.

4.3.4 Interview with autonomous developer

The interviewee explains that there are many actors within remote operation with big visions, nevertheless there is not always a business case.

"For example, if one person is going to sit and steer one vessel with a joystick, we do not have a business case, then we might as well have him on board, but if we might, for example, take the USVs that are going to steer ROVs, then you substitute a ROV vessel, that has 90-110 persons on board, there you have big money."

A USV with clients will need a safety host, someone who can maintain the safety on board, however the navigation itself can be done by an SCC. There would also need to be a set of minimum risk conditions. If autonomy is proven to be safe enough, it will be hard to withstand approving it for use, but sufficient safety barriers are a must. A navigator has other tasks than just navigation, like handling passengers. An alternative would be to train the clients, which would then become a part of the safe manning requirement. The solution for remote or autonomous operations is to find equivalent solutions for a reasonable price.

4.3.4.1 Operator on autonomous ships

The interviewee pointed out that the technology must support the safety aspects contributing to eliminating human error, such as fatigue, laziness, and lack of attention, regardless of whether being a fully autonomous vessel or just on a supportive level. The perfect operator manages to combine what is on a screen and what is outside the window. The interviewee argued that a DP system is much safer than a human, it is a safety tool with a lot of barriers, but it deprives the navigator of the overview, especially when something goes wrong.

4.3.4.2 Control room operator

Initially the role as an SCC operator would be fulfilled by a navigator that has experience from vessels. Obtaining situation awareness must be achieved in the SCC, and safety must be maintained through several layers.

"That is something that you have to evaluate for every autonomous approval. That will increase the awareness and focus that you need safe barriers the whole way. There you will get a couple of layers of safety that you are lacking today."

The training will become more technical and focused on problem solving. The interviewee meant that the roles would be combined, one person might manage the engine and navigation. When asked if vessel maneuvering 12 hours per day could be compared to some weeks of simulator exercises per year, the interviewee mentioned that captains today are sometimes in a similar situation.

"You can compare it to a captain, who has been a captain in 15 years and never been on the bridge, he still has his certificate. But one error does not justify another. There is a difference between driving a vessel physically, locally and through simulation."

4.3.4.3 Unmanned bridge and regaining situation awareness

A method for immediately regaining situation awareness must be developed and the transition must be made without complications. That can be done with alarms, when a navigator should be alarmed, when not and which information is passed on. The transition must be maintained with a combination of technical tools and management procedures. On an autonomous ship, there would be safety barriers that maintains control over the vessel until the operator reaches the bridge, as well as alarms and safety barriers assisting the operator when having the wrong perspective of things. Situation awareness must be handled genuinely and as simple as possible, without faults and complications.

4.3.4.4 Ship sense

Ship sense should be considered, but it is not necessarily a 'show stopper'. It is possible to measure and compensate for the movements affecting the vessel. It might be necessary to apply some parameters to address the movements, which can be presented to the operator.

4.3.4.5 Human-machine interaction issues

When asked about the largest HMI issues, the interviewee mentioned good seamanship, difference in perspectives and consequences. A computer might compare outcomes using parameters such as cost, while a human might consider soft values when making decisions. The interviewee mentioned that both options could nevertheless be done safely. A system with applied minimum risk conditions and safety barriers will lead to over-reliance over time.

"That over-reliance on the system will develop over time, it is dependent that you have a couple of safety barriers to uphold that you are attentive over time, if you have systems then that applies these barriers, and removes the human errors. We humans have traits that the systems can help us with or remove us due to."

4.3.4.6 Bridge and SCC design

Everything unnecessary should be removed, and everything should be operated from one conning position. However, in a control room, it will be dependent on which setup that has been decided for, the focus should however be on situation awareness.

5   Discussion

This chapter will address the research question in light of the data collected from the interviewees. These interpretations will be tempered with identified limitations and delimitations of the study. Statements from the interviewees from the results section are referred to using their respective subcategory. The conclusion of the practical deployment of automation-based technology to substitute or improve each goal-based task is presented in figure 9 and 10 at the end of the discussion chapter.

The following research question is considered in this thesis:

- How practical, from a safety of operations perspective, is it to deploy automation-based technologies to substitute or improve goal-based DP operations?

5.1   Key findings

The DPOs' standpoints regarding the deployment of automation-based technology were aligned concerning some tasks, while others were diverging. Relieving DPOs of some of their tasks through either-or autonomous and remote handling was perceived as positive. Removing people from the vessel entirely was not an option, mainly due to the necessity of emergency preparedness.

Tasks considered repetitive (4.2.8, 4.3.4), low-risk (4.2.2), and less complicated (4.2.4) could easily be substituted with automation-based technology, while tasks considered unpredictable (4.2.1) and unusual (4.2.11), with limited response time (4.2.2, 4.2.4) and high-risk (4.2.5, 4.2.7, 4.2.2, 4.2.7, 4.2.11), could not be substituted and therefore requiring an additional human barrier (4.2.4). Automation-based technology might keep an operator out of the loop (4.2.1), lowering situation awareness (4.2.6, 4.3.1) and response ability (4.2.4). Kinesthetic feedback makes out an obstacle when adopting remote solutions (4.2.4, 4.2.5, 4.2.7, 4.2.13). Verification of actions and decisions made by automation-based technology should be allocated to humans to a certain degree, partly due to logical (4.2.4) and ethical aspects (4.3.4.5). Humans were viewed as a second layer of redundancy, able to perceive situations in a differently than a technical system (4.2.7).

5.2   Logging

In general, the interviewees considered logging as an activity that can be done fully autonomous, possibly relieving one member of the bridge team. However, autonomous logging

was problematized due to legislative issues (4.2.3). The legislative issues must be sorted before taking autonomous logging in use.

A logging failure would not impose any immediate danger and can therefore be placed on the fully autonomous level. Since logging can be handled by automation-based technology solemnly, there is no need for remote intervention, which is in line with the opinions of the DPOs (4.2.3).

5.3 Response, monitoring, maneuvering and navigation

Response, monitoring, maneuvering and navigation will be discussed collectively because they are deemed as being interrelated and affected by the same mechanisms enabling or restricting automation-based technology. The identified mechanisms are ship sense, situation awareness, interface issues, and soft skills.

5.3.1 Situation awareness and ship sense

None of the DPOs used the word ship sense, instead they described sensory impressions of the vessel movements, external forces acting on the vessel, and thruster and engine vibrations. In the results section, these descriptions were replaced by the term 'Kinesthetic feedback'. However, it is reasonable to conclude that the descriptions made by the DPOs and ship sense are comparable.

TNO (2017) argued that due to the lack of situation awareness, an operator cannot interfere quickly and effectively in the case of a failure on an autonomous system. This is prevalent during DP operations where there is a short response time available, while the chance of preventing an accident lessens with time (Chen and Moan, 2003; Sandhåland et al., 2015). The interviewees did mention that some DP operations are more critical than others (4.2.4, 4.2.7), characterized by a short 1response time and need for kinesthetic feedback (4.2.4). An autonomous system might make out a better alternative when working within the operational limits (4.2.4) or during low-risk tasks (4.2.2), while a human might be a better alternative whenever working outside of the limits (4.2.4).

An operator of a highly autonomous system will struggle making the correct decisions at the right time (4.2.1). Highly automated autonomous systems are essentially controlling all components themselves, which means that the operator would only interfere whenever the system fails and thus does not need to constantly be aware of the system operation (TNO, 2017). The interviewees also concluded that an operator does not need to maintain situation

awareness and are neither good at it (4.3.1), but automation must help the operator gain situation awareness when required (4.3.1, 4.3.4.3). However, lacking situation awareness while a critical situation arises is problematic (4.3.1). Endsley (2017) said that operators will overlook critical information when the automation becomes more robust and reliable, keeping them from taking command when necessary. Endsley (1995) also points out that operators detect problems slower if their situation awareness is degraded.

Gaining situation awareness takes time (Bainbridge, 1983), and must be maintained for an operator to remain in the loop and keep track of the dynamic situation (Porathe et al., 2014). One interviewee also mentioned the importance of achieving situation awareness (4.3.4.2) and remaining attentive over time (4.3.4.5). However, autonomous systems often deprive the operator of obtaining situation awareness (4.3.4.1).

An autonomous system can exclude human errors (4.2.1), but once taking control of a vessel, the operator is faced with system failures previously compensated for by the autonomous system (Bainbridge, 1983). Additionally, the operator will often have a lower perceived risk (Saffarian et al., 2012). When excluded from the loop, the operator will lack sufficient context to make the correct decisions even with new skills and knowledge (Bradshaw et al., 2013). When monitoring automation in place of being in control manually, an operator's performance declines (Farrell and Lewandowsky, 2000, 4.2.1), characterized by limited decision making, knowledge and situation awareness (4.2.1). When excluded from the decision-making process, the operator will be left monitoring if the computer is making "acceptable" decisions (Bainbridge, 1983). Degraded situation awareness and ineffective monitoring combined with an over-reliance on automation can lead to a startled response when an operator is facing a sudden automation failure (Jarvis et al., 2014). Existing skills will degenerate over time (4.2.13) when not practiced, but extensive training might maintain them (4.2.1) and improve situation awareness (4.2.7).

The DPOs in the TNO (2017) study were optimistic to the concept and opportunity of roaming but were reluctant to leave the bridge. Some of the interviewees were not comfortable leaving the bridge (4.2.11). The interviewees' skepticism leaving the bridge were partly due to difficulties regaining situation awareness (4.2.12). About half of the interviewees stressed the need of having someone on the bridge to monitor high-risk situations, out of the ordinary (4.2.11).

Ship sense was first accounted for by the captain once he could feel the movements (4.3.1). However, it seems like an operator can get used to relocating from a vessel with a bit of time and the right measures, as seen with the crane operators and the ROV operators (4.3.3.2, 4.3.3.1). But it might be difficult to account for certain factors lacking the experience from a real vessel (4.3.3.2), which can also be seen among drone pilots (4.3.2)

Ship sense should somehow be transferred to the SCC (Wahlström et al., 2015), but failing to do so is not a 'show stopper' (4.3.4.4). According to Man et. al., (2015) an operator can get an understanding of the environmental prerequisites through information provided by ship sensors and navigational instruments, the interviewees also mention that sensory impressions can be compensated by supplying relevant information (4.3.3.2, 4.3.4.4). However, it will be difficult for an operator to interpret contextual information (Wahlström et al. 2015) and an operator in an SCC is not in the loop as an officer on a ship would be (Man et al., 2015). Four of the DPOs state that someone is required onboard the vessel due to ship sense (4.2.4), an operator on board knows how a sudden change of external factors will affect the vessel before it happens (4.2.6).

Some DP tasks require high position accuracy, which is affected by the external and internal forces acting on the vessel. When transferring tasks that require high position accuracy to an SCC it will be vital to also transfer ship sense. An operator's ability to respond will depend on previous experience and to which degree ship sense is successfully transferred to an SCC. Both academia and interviewees argue that ship sense is significant, and that effort should be made to account for ship sense when designing an SCC, even if it might not be decisive. There should be enough time for the operator to get back into the loop and develop situation awareness to manage the situation like someone on board. There are several examples of one's ability to adapt to new situations and contexts. The ability to interpret ship sense only using cameras and system projections can be increased through practice. However, such practice might not have the same effect on those who have never been on board a vessel. A system could be programmed to accommodate a rapid increase in situation awareness, however, during the most critical tasks, it might not be sufficient. Latency can add constraint and complication to a remote operation, in addition to the time required to regain situation awareness.

It can be concluded that over confidence, automated-induced complacency, and a lack of situation awareness all together will decrease an operator's ability to respond effectively at the right point in time. It can be argued that an operator engaged in DP tasks considered high-risk must be in the loop, which requires situation awareness, including ship sense. The operator will

require time to get in the loop and regain situation awareness. Consequently, tasks considered high-risk require that the operator is already in the loop when the task is initiated. It would be reasonable to conclude that tasks where human lives are at stake while the response time is short should not be allocated to an automation-deployed technology without a human on board with sufficient situation awareness and skills, ready to take control of the vessel.

5.3.2 Interface issues

An operator, who is not engaged when the system is operational, is expected to adequately operate the system when the system itself is incapable (Bainbridge, 1983). An operator must also judge whether a system is coping with the current situation and when to intervene (4.3.1), but overconfidence and decreased monitoring performance will result in difficulties detecting critical deviations and act in unanticipated situations (Hogg & Ghosh, 2016). Additionally, an operator will only notice when there are abnormalities in what they perceive as their task but might not notice abnormalities normally seen as the task of the automated system, especially if the system has proven to work effectively for a longer period of time (Bainbridge, 1983). Automated-induced complacency affects both experienced and new operators, it is thereby not reduced by experience or practice according to Parasuraman and Manzey (2010). One of the interviewees mentioned that when things are being sorted by an autonomous system, one easily becomes complacent (4.2.7).

The DPOs had the impression that programmers do not have the necessary knowledge of how a vessel is operated (4.2.1), additionally, it might be difficult for a programmer to program for every possible outcome (4.2.2). They also state that the limitations of a system like the DP, is that it can never be better than it is programmed to be (4.2.1). When technology is programed, it will be difficult to remove humans and their accompanied human errors from the equation as mentioned by Bibby et al. (1975) and Bainbridge (1983). A DPO will make decisions based on experience and knowledge (4.2.6), while an autonomous system will make decisions based on large quantities of data (4.2.4). By considering other aspects, humans are adding redundancy to an autonomous system (4.2.6), which added technology is unable to.

The DPOs often experienced the DP system to struggle with basic faults, however these were not resolved by the producer (4.2.11), which sometimes required the operator to manually compensate for the faults (4.2.1). One could think that the DPOs might have the impression that they are not being taken seriously when their feedbacks to the DP developers are not being accounted for. In some cases, the system solutions are so unbeneficial that it might not make

sense to use them, such as the docking mode explained by one of the DPOs (4.2.7). The interviewee working within remote solutions for ROV operators, said that his experience being a DPO was that the systems on board do not work as intended because they are not yet finished when installed (4.3.3.2). The interviewee understands why operators are doubting the use of autonomous vessels, when thinking about the development of the DP system (4.3.3.2).

According to Hogg & Ghosh (2016), An operator who lacks trust in the automatic system might not be able to use it to its full potential. Both when a fault occurs and which consequences that fault causes are factors affecting trust (Hoff & Bashir, 2015; Manzey et al., 2012; Sanchez, 2006). Automation errors related to tasks perceived as easy will have greater impact on trust compared to tasks perceived as difficult (Hoff & Bashir, 2015). An autonomous system is expected to take on complex tasks. Meanwhile basic faults or absence of basic features are present today, such as getting the correct nacelle heading (4.2.5) or docking mode (4.2.7), such faults and absences arguably affect the operator's trust. Additionally, being blamed for actions taken by automation-based technology without being in control as an operator (Awad et al., 2018), does not increase the willingness of an operator to let automation-based technology control anything.

The interviewee working within remote operations mentioned that he believes some developers in the industry have an attitude that everything can be solved technically (4.3.3.2) One of the other interviewees within automation is saying that technology must mitigate human error (4.3.4.1), while the autonomous logistics developer stressed the importance of a simple and easily understandable interface, enabling optimal learning (4.3.2). When an autonomous system is working flawlessly for a longer period of time, an operator would start to relax until an incident occurs and consequently, more attention will be paid to the system until the incident is repressed (4.2.5).

The interviewees' previous experience with autonomous systems certainly affects their attitude and trust towards similar technological solutions and could also affect their potential as an operator. Technology can be added to reduce or mitigate human error, but it would be reasonable to conclude that not every "human error" can be accounted for by adding more technology. If human lives are not to be endangered, it would not make sense to use technology that is perceived as untrustworthy. The issue with human-machine interaction and interface is not the capabilities and knowledge of humans, it is the technology's lacking ability to accommodate a prosperous cooperation between the two.

Awad et al. (2018) studied if humans were blamed in accidents involving autonomous vehicles. When both a human and an autonomous system were driving, less blame was attributed to the autonomous system. When the autonomous system was solely in control of the driving, the blame was nevertheless partially attributed to humans, for example blaming the passengers or the producer even though the autonomous system is in full control.

5.3.3 Soft skills

Gut feeling, experience, drawing logical conclusions, reasoning, consequence analysis, understanding other humans, thinking *outside the box*, and interpretation are all aspects that the DPOs mentioned as troubling when replacing humans with technology (4.2.1, 4.2.9). One of the interviewees working with autonomous solutions pointed out seamanship, different perspectives, and consequences as the largest human-machine interaction issues (4.3.4.5). Humans and autonomous systems might have different consequence parameters (4.3.4.5). Some of these concerns were also brought forward by Wahlström et al., (2015), who pointed out that object identification and evaluation might be different between humans and autonomous system, not only relating the navigational aspect, but also security, empathy, and communication. The ability to identify objects was also brought up by two of the interviewees as an issue when allocating navigation tasks to automation-deployed technology (4.2.9). Both Wahlström et al., (2015) and the interviewees mentioned the difficulties understanding implicit intentions, such as the COLREG rule no. 21, communication between vessels (4.2.9) or interpreting requests made by humans, which might become even more important during emergencies (4.2.8).

Several of the interviewees pointed out abilities that are possessed by humans exclusively. These abilities might make out a fundamental difference when operating a vessel with humans on board. In critical situations, where interpretation, communication and empathy can make a great difference to how a situation is handled, it will be vital to maintain the human perspective and values.

5.3.4 Response

The DPOs meant that response can be handled by an autonomous system with a degree of approval from an operator. Daily tasks and less complicated situations could be suitable for autonomous response. None of the DPOs considered the possibility of a fully autonomous response. Factors limiting automation-deployed technology include skills possessed by humans exclusively, kinesthetic feedback, and limited response time (4.2.4).

An immediate response or lack of response by an autonomous system or an operator lacking situation awareness during critical operations imposes a danger to the vessel and the people on board. Thereby, critical operations response can be placed on an automatic level, provided the operator has a high level of situation awareness, sufficient training, and knowledge. During less critical operations, response can be placed on a constrained autonomous level. The factors limiting remote handling, as mentioned by the interviewees might not have to be considered during operational situations where they do not make out a difference. Less critical tasks can be allocated to an operator at an SCC. Critical operations require situation awareness, including ship sense that might only be gained sufficiently on board a vessel.

5.3.5   Monitoring

It was generally considered that technology could take on a greater role in monitoring the DP operation. Human life at risk and interface issues were some of the factors limiting fully autonomous monitoring. Kinesthetic feedback and connection delays were mentioned as factors making remote monitoring difficult. One interviewee pointed out that it might be better to monitor from ashore due to less distractions (4.2.5).

System monitoring should be placed on a level where it can cope effectively with emerging situations, thereby not damaging the operator's trust. Monitoring is a precursor to building situation awareness and helps the operator respond effectively, which is vital during critical operations which impose danger to the vessel and the people on board. The limitations of autonomous or remote monitoring operations affect the possibility of an autonomous or remote response since monitoring is necessary to detect when to respond. Thereby, monitoring of critical operations can be placed on an automatic level. During less critical operations, monitoring can be placed on a constrained autonomous level. Monitoring can be allocated to an operator at an SCC. However, critical situations might require a response from an operator on board, which means that even if a human is monitoring from ashore during, an operator on board must be available to respond with sufficient ship sense and information foundation.

5.3.6   Maneuvering

Maneuvering was perceived as an activity that could be done autonomously or remotely to a certain degree. Transiting between turbines and to and from the wind farm can be done by an autonomous system or remotely, contrary to high-risk tasks such as maneuvering next to installations. The interviewees highlighted the importance of kinesthetic feedback, situation awareness, training, soft skills, and qualities obtained by humans exclusively. An operator

should decide what to do in an emergency, including overriding and final decision making (4.2.7).

High-risk operations and emergency maneuvering require an additional human redundancy with sufficient ship sense, situation awareness and training to handle any maneuvering situation. All other maneuvering tasks can be handled by automation-deployed technology, given that an operator's situation awareness and ship sense is sufficient for the respective tasks, so that a response can be initiated when needed. Thereby, maneuvering can be placed on an automatic level or on a constrained autonomous level. Less critical operations can be allocated to an operator at an SCC.

5.3.7 Navigation

The interviewees were generally positive to autonomous-deployed navigation. Collision avoidance, planning and keeping outlook were considered tasks that could be handled autonomously. However, there's a need for verifying the actions of the autonomous system. Allocating to technology might be a safer alternative, much depending on the human alternative. The difference between how humans think and how an autonomous system is programmed to think can cause problems (4.2.9).

Navigation can be placed on an automatic level or on a constrained autonomous level, depending on if the task is considered critical or not. Navigation can safely be allocated to an operator at an SCC, since most limiting factors brought forward by the interviewees are connected to soft skills, which are mitigated when an operator is in control.

5.4 Communication

Some parts of communication were considered easily transferred to an autonomous system. Emergency communication and communication with clients were stated as being less likely feasible by an autonomous system. Communication between two DPOs might suffer when one of them is placed ashore. But communication between departments might improve when being placed together in an SCC (4.2.8). But it might affect bridge resource management, which in turn affects safety on board.

An autonomous system will likely be able to communicate larger quantities of information more accurately than a human. Consequently, communication based on data can be placed on a fully autonomous level, and thereby does not require any remote intervention. However,

communication between humans should remain between humans, that includes remote communication but excludes any involvement from an autonomous system.

5.5   Human factors

Social interactions have been identified to be a prerequisite to autonomous or remote operations rather than a goal-based task. The ethnographic study did not manage to capture the social aspect, which might be because it would not be considered a goal-based task. The social and ethical dilemmas of autonomous and remote steering have not been considered in this thesis. However, they are considered important enough to be mentioned by the interviewees even when neglected to be asked by the interviewer. It might be concluded that ethical and social factors should be considered a prerequisite equal to legal, economic, and technological factors. Thereby the suitable allocation is not further elaborated.

5.6   Waiting on weather

Only one of the DPOs brought up weather waiting. An autonomous vessel can struggle to comprehend which movements are best for the vessel and people on board, relating to the system's ability to understand ship sense (4.2.14).

Waiting on weather is not by itself identified to pose any immediate danger to the vessel. However, adverse weather might pose a risk or discomfort to the remaining people on board and the vessel. It would be reasonable to conclude that waiting on weather can be allocated either to a constrained autonomous, a fully autonomous level or an SCC depending on the technological advancement and the risk factors posed by the current location of the vessel.

5.7   Emergency response

It is difficult to foresee the course of an emergency beforehand. When having clients on board it will be necessary to have a minimum manning according to some of the DPOs (4.2.6). One of the developers within remote and autonomous steering mentioned that a USV will need a safety host or train the clients (4.3.4).

The crew is usually appointed by the vessel's owner or operator, and therefore usually on board during several projects. While a client is on hire for one project only. It could be argued that a client is in general less experienced with the specific vessel compared to what a crewmember would be.

Many of the concerns brought up by the interviewees cannot be considered related to DP operation, but general emergencies. The general emergency preparedness does not necessarily

involve a DP operator, but as long as there are people on board, there should also be emergency response team available onboard.

During emergencies, all available aids should be mobilized to inhibit the consequences. When having people on board, the minimum crewing requirement should sustain to enable an effective emergency handling. In addition to the minimum crewing, autonomous and remote aids will complement the on board emergency preparedness. Responses which do not pose a risk to the vessel or humans on board can be automatically initiated by an autonomous system or a remote operator. However, all responses that might pose a risk to the vessel or the humans on board should be initiated by the vessel's crew. Emergency response can thereby be allocated to either a decision support or an automatic level of autonomy depending on the imposed risk.

5.8   Limitations and weaknesses of the study

The four levels of autonomy by Rødseth & Nordahl (2017) are defined in relation to a ship's capability of operating without human intervention. When allocating the goal-based tasks, the levels of autonomy have been applied in relation to human intervention, not necessarily in relation to the level of technology needed to execute certain tasks.

The researcher and the first interviewed developer were not asked to answer the questions based on the same limitations as other interviewees, those limitations being SOVs maneuvering through a DP system within a wind farm. Their answers can thereby be generally applicable for remote and autonomous handling, but not specifically within the set limitations as mentioned earlier.

The DPOs were all working for the same company, which might have affected both the ethnographic study and the interviews due to coherent factors within the company which are not necessarily applicable to other companies. That can for example be procedures and other parts of the safety management system. Informing a larger number of potential interviewees about the study, rather than requesting specific interviewees to participate, could have mitigated the need to exclude one of the interviewees due to lack of engagement. Presumably, the chances of only interviewing participants who would have had a genuine interest in the study would increase when the interviewees themselves apply to participate.

There could be an interest conflict and attitude differences between the interviewees. It could be assumed that developers of autonomous or remote systems have a more positive view of their respective use, compared to the DPOs who might lose their jobs due to them. It could also

be argued that developers are focusing more on getting remote steering or autonomous vessels working technically, while the operators would be more concerned with user related issues.

The interviewees had a varying degree of knowledge and optimism towards autonomous or remote operations, however they always argued for the levels on which they allocated the tasks. Quite often the interviewees would have the same arguments, nevertheless allocating the task on different autonomous levels. Some interviewees prepared according to the survey while others prepared less, nevertheless they were all engaged in the semi structured interview, apart from the interview that was excluded. Even though all the DPOs received the same instructions and questions, they focused on very different things. This could be due to their previous knowledge and interview engagement, but it could also be that the questionnaire was not designed well. A sufficient level of knowledge regarding autonomous and remote operations should have been assured be the interviewee before commencing with the interviews. The difference in focus among the interviewees might be due to personal experience.

Economic aspects, level of technological advancement, laws, regulations, guidelines, or other factors that might affect the advancement of MASS and DP operations were not to be reviewed in this thesis. However, it would be naïve to answer the research question while disregarding these factors. Therefore, these factors have been included in the results chapter when deemed relevant.

The theory is mostly relating to the following goal-based tasks: response, monitoring, maneuvering and navigation. There is a lack of theory relating to the other goal-based tasks. However, the arguments supporting or opposing deployment of automation-based technology for the remaining tasks spring from logical or operational assumptions rather than theoretical.

5.9   Summary

Tasks conducted during DP operations in windfarms can be, to some extent, improved or substituted by automation-based technologies, as seen in figure 9 and 10. It is possible to remove parts of the crew, but not entirely. Even though economic aspects were not considered in this thesis, it is worth noting that the economic gain and business case are potentially non-existent due to the small fraction of crew that can be moved. However, there might be other reasons than economic one's motivating deployment of automation-based technologies.
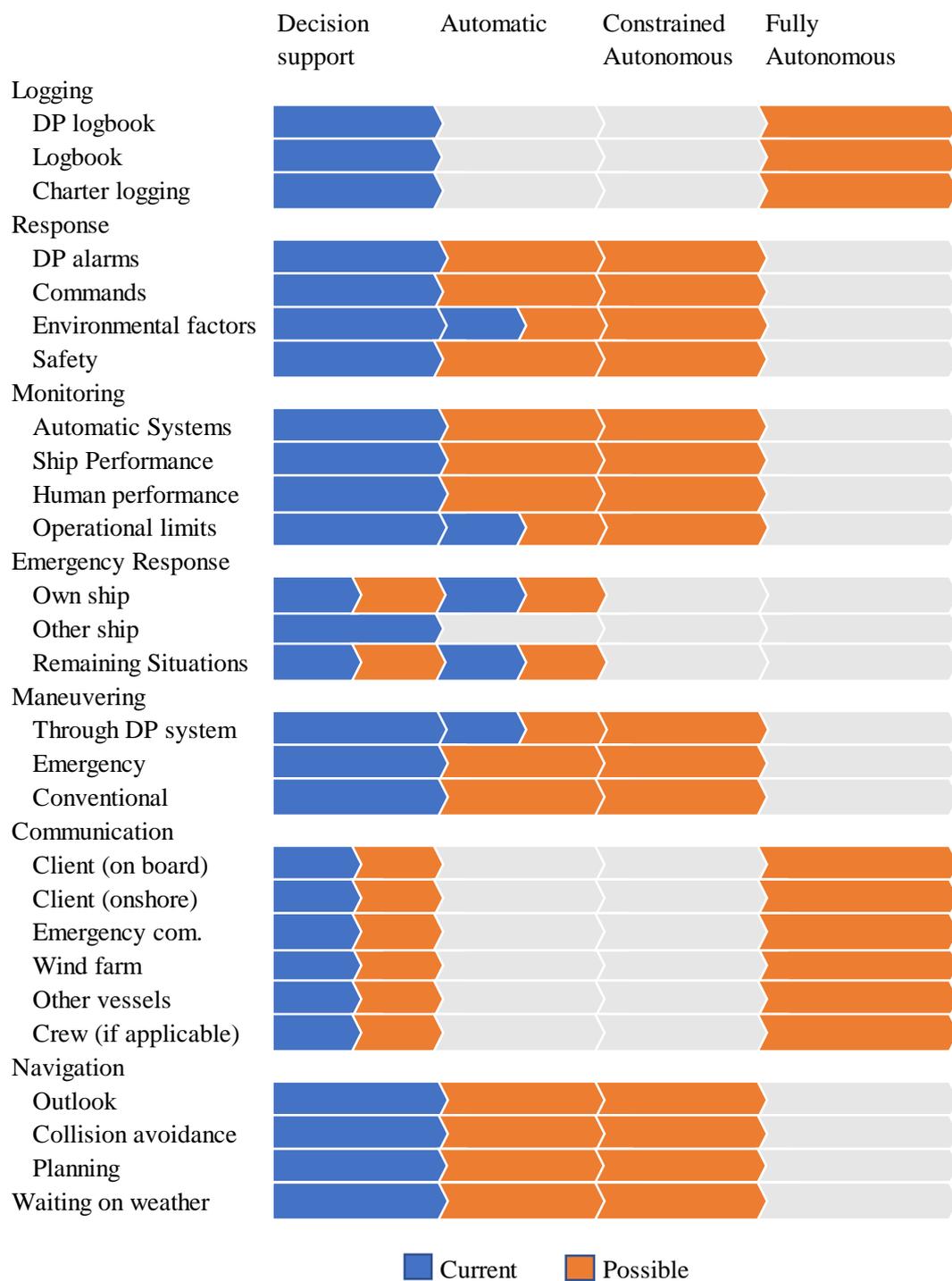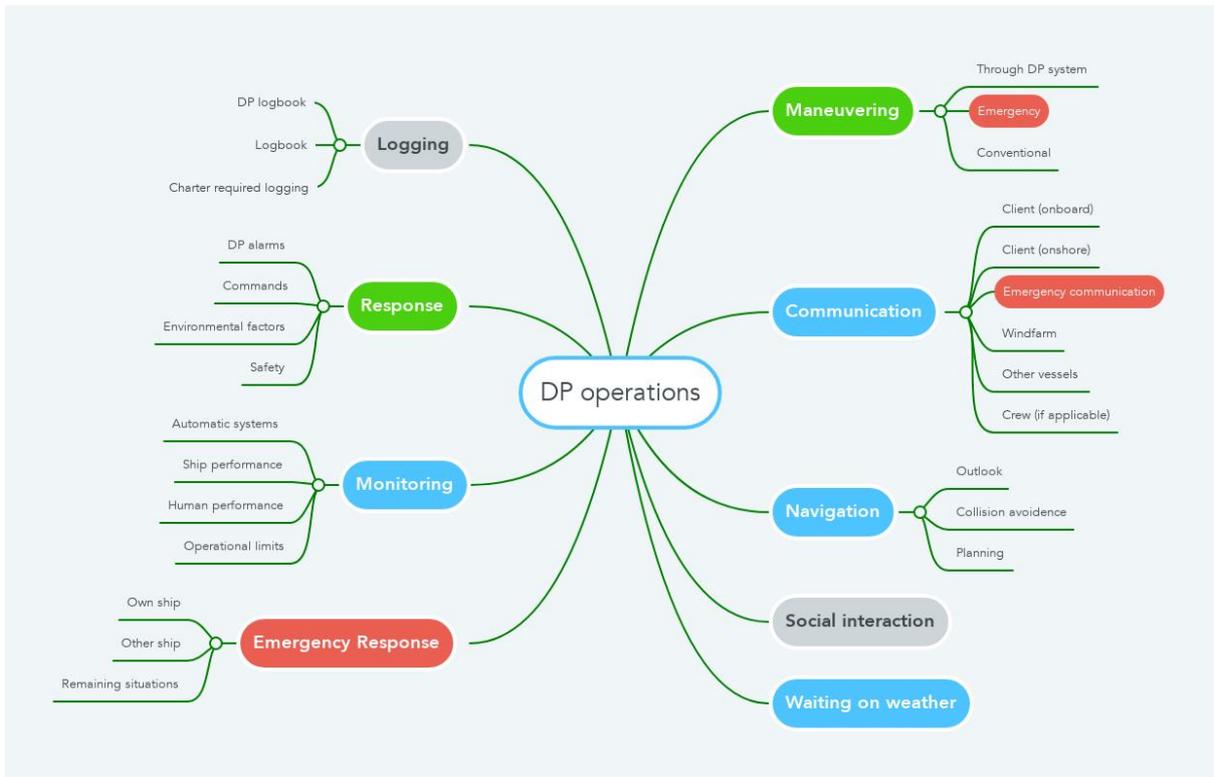
Figure 9. Current and possible autonomous task allocation

■ Can safely be allocated to an operator at an SCC
■ Can safely be allocated to an operator at an SCC
   during uncritical situations
■ Cannot be safely allocated to a remote location
□ Not applicable

Figure 10. Possible remote task allocation

6 Conclusions

Taking human-machine interaction into consideration when developing automation-based systems might make out the difference between a safe and unsafe system. A prerequisite for the task allocation, as stated in the limitations section, is that the outcome should not result in a less safe, secure, and reliable DP operation. Both developers and DPOs stated that an autonomous system might fulfill these prerequisites. Nevertheless, a human will add redundancy, differing from any other form of redundancy.

It has been argued throughout the discussion that some tasks ought not to be allocated to any other party than an operator on board. This puts focus on bridge and SCC design, and training requirements. There is no doubt that humans are agile and adaptable. Sufficient training and technical solutions can enable well-functioning remote and autonomous solutions. However, in the wind farm industry it is not possible to neglect the risk imposed by the specific kind of operation. The issues are many and diverse, with the correct interventions, some of these issues can be accounted for. However, when human lives are at stake, it might not be sufficient. Due to the difficulty of regaining situation awareness, transferring ship sense, and limited response times, the most critical tasks should be monitored by a DPO on board with a high level of situation awareness and sufficient conventional and technical knowledge. The alternative would be to lower the operational limits. The operational limits might be restored in the future with the right interventions to combat the human-machine interaction issues brought forward in this thesis.

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8 Appendices

Appendix 1 – First semi-structured interview questionnaire

Survey / Interviews

- How did the introduction of Radar/ECDIS/AIS/DP affect a navigator?
- Which skills did you need to develop to embrace the possibilities and use the new equipment?
- Which important skills might be lacking when the traditional way of conducting navigation is not taught (in comparison with learning how to use the current/future technology)
- Do we have too much confidence in the current technology? How does that affect safety?
- Regulations? How can we solve/face the regulatory challenges?
- Where is the current gap? What would be the consequences of putting me in a shore control center? What will be the largest challenges when transitioning from the shipping industry per today to the future of MASS?
- What are the consequences of autonomy?
- As an example, the SA, how do we deal with that? How do we make sure that an operator will keep their SA up to date? What are the solutions?
- Let's say the SA is low, nothing is happening -> tech/human not working good as a team -> do we change the human or technology? Education or technological adaption? Technological features based on the operator for example?
- Adaptive technology/situation awareness – will this make the operator overlook important/relevant info that might not be projected? Will it make the operators lazy?
- Where do we find the largest challenges regarding socio-technical systems?
- From my own experience, operators of DP systems have very different knowledge and skill levels depending on the vessel and type of tasks.
- The first problem is the knowledge and understanding of the system itself, while the second problem is the vessel capabilities and how it is affected by secondary forces.
- How do we make sure that these problems don't reoccur for operators at SCCs?
- How do we make sure that they have sufficient knowledge about the system itself? And how do we make sure that they understand the vessel and its capabilities/limitations?

- Do you see the technology moving towards being adapted towards humans, or do humans need to adapt towards the technology?
- Which qualities does a good operator have? And which knowledge does an operator need to develop?
- I also notice that people are uncomfortable outside of their daily operations. How can we make sure that the operators maintain "their" traditional skills?

General Questions

- What makes a good operator? Which skills do you need? Is it something you have from before or can you learn to become a good operator?
- How do you keep your SA? Does anything help you to keep up your SA? What affects your SA negatively? Could something that will increase your SA have a negative impact on other parts of your job?
- Which of these skills would you value the most?
- What were the problems? How did you solve them? Which technology was introduced? Did the operator have to change to make this technology work?
- Which kind of person is comfortable with technology?
- How do you recruit persons?
- What is your setup of a SCC like? How are you planning on monitoring the Yara? (I understood that the setup could be different compared to the MUNIN project)
- Are you looking at the possible human-machine interaction issues for the moment? Or are you mostly looking at the technical aspect?

Skills

- Which skills would you need to work as an operator in an SCC?
- If you would hire an operator, which qualities would you look for in that person?

Human-machine interaction issues

Have you taken measures for the following issues? And what is required by an operator to handle these issues in daily operation?

- Trust
- Automated induced complacency
- SA
- Ship sense
- Information overload
- The ability to remain in the "loop"

At last, how should we educate future operators at SCCs?

Appendix 3 – Third semi-structured interview questionnaire

Remote operations

- Is there any difference between operating an ROV/USV from a ship and an SCC?
- Regarding your day-to-day remote operations, which problems and opportunities have been enabled through a remote operation of a ROV/USV?
- How have you adapted your day-to-day operation to face the challenges of remotely operating an ROV/USV? (What were the problems? How did you solve them? Which technology was introduced? Did the operator have to adapt to make this technology work?)
- Do we have too much confidence in the current technology? How does that affect safety?
- How does your operations contribute to lessen environmental print and lowering operating expenses?
- Which type of vessels are to be part of the USV fleet?
- What is your setup of a SCC like?
- Are you looking at the possible human-machine interaction issues for the moment? Or are you mostly looking at the technical aspect?

Operator

- Which skills/education make a good operator of remote vehicles (ROV/USV)? Which skills do you need? Is it something you have from before or can you learn to become a good operator?
- How many ROVs does one person control?
- Where is the current gap? What would be the consequences of putting a navigator in a shore control center? What will be the largest challenges when transitioning from the shipping industry per today to the future of MASS/USV?
- Should technology be adapted towards humans, or do humans need to adapt towards technology?
- How can we make sure that an operator maintains "their" traditional skills?
- What are the consequences of autonomy? What could be the challenges of transiting towards a more autonomous bridge operation?
- Where do we find the largest challenges regarding socio-technical systems?

- How do we make sure that an operator has sufficient knowledge about the system itself? And how do we make sure that they understand the vessel and its capabilities/limitations?
- Do you have a proactive strategy to meet the challenges of the use of USVs?

Human-machine interaction issues

Have you taken measures for the following issues? And what is required by an operator to handle these issues in daily operation?

- Trust
- Automated induced complacency
- SA
- Ship sense
- Information overload
- The ability to remain in the "loop"

- Which tasks are practically allocated from a DPO to an autonomous system or an SCC?
- What is your vision for bridge automation?
- Do we have too much confidence in the current technology? How does that affect safety?
- Are you looking at the possible human-machine interaction issues for the moment? Or are you mostly looking at the technical aspect?
- Which skills/education make a good operator? Which skills do you need? Is it something you have from before or can you learn to become a good operator?
- Where is the current gap? What would be the consequences of putting a navigator in a shore control center? What will be the largest challenges when transitioning from the shipping industry per today to the future of MASS?
- What are the consequences of autonomy? What could be the challenges of transiting towards a more autonomous bridge operation?
- Where do we find the largest challenges regarding socio-technical systems?
- How do we make sure that an operator has sufficient knowledge about the system itself? And how do we make sure that they understand the vessel and its capabilities/limitations?
- Which kind of person will work in an SCC, which background would that person have?

Human-machine interaction issues

Have you taken measures for the following issues? And what is required by an operator to handle these issues in daily operation?

- Trust
- Automated induced complacency
- SA
- Ship sense
- Information overload
- The ability to remain in the "loop"

Survey background and instructions

The goal of the thesis is to evaluate if autonomy can have a role in future dynamic positioning operations. In this document you will find the instructions for a survey, which will be followed by an interview whenever you are finished. Remember to read through, sign and send the consent form before you begin. If you have any questions, please call, or write me.

Please do not share information or thoughts with other interviewees of this study. By sharing information and thoughts with others, you might alter the results of this study.

The thesis is aimed at answering the following research question:

- How practical, from a safety of operations perspective, is it to deploy automation-based technologies to substitute or improve goal-based DP operations?

A literature study along with interviews with academic representatives and developers within the field of autonomy has already been conducted. A disguised naturalistic ethnographic study has outlined the goal-based task allocation matrix on page 3.

- Please look thoroughly through the task analysis. Reflect over your role as a DPO and your everyday tasks related to daily operations. Would you add or remove any categories or subcategories to it?

The Norwegian Forum for Autonomous Ships (NFAS) defined four levels of autonomy in their publication "Definitions for Autonomous Merchant Ships": Decisions support, automatic, constrained and fully autonomous (Rødseth & Nordahl, 2017).

- Decision support is defined as "corresponds to today's and tomorrow's advanced ship types with relatively advanced anti-collision radars (ARPA), electronic chart systems and common automation systems like autopilot or track pilots. The crew is still in direct command of ship operations and continuously supervises all operations. This level normally corresponds to "no autonomy"" (Rødseth & Nordahl, 2017, p.11)
- The automatic level is defined as "The ship has more advanced automation systems that can complete certain demanding operations without human interaction, e.g. dynamic positioning or automatic berthing. The operation follows a pre-programmed sequence and will request human intervention if any unexpected events occur or when the operation completes. The shore control centre (SCC) or the bridge crew is always available to intervene and initiate remote or direct control when needed." (Rødseth & Nordahl, 2017, p. 11)
- Constrained autonomous is defined as "The ship can operate fully automatic in most situations and has a predefined selection of options for solving commonly encountered problems, e.g. collision avoidance. It has defined limits to the options it can use to solve problems, e.g. maximum deviation from planned track or arrival time. It will call on human operators to intervene if the problems cannot be solved within these constraints. The SCC or bridge personnel continuously supervises the operations and will take immediate control when requested to by the system.

Otherwise, the system will be expected to operate safely by itself." (Rødseth & Nordahl, 2017, p. 11)

- Fully autonomous is defined as "The ship handles all situations by itself. This implies that one will not have an SCC or any bridge personnel at all. This may be a realistic alternative for operations over short distances and in very controlled environments. However, and in a shorter time perspective, this is an unlikely scenario as it implies very high complexity in ship systems and correspondingly high-risks for malfunctions and loss of system." (Rødseth & Nordahl, 2017, p.12)

On the last page you will find the autonomous matrix.

- Please allocate the tasks in whichever category of autonomy that you believe is feasible. As an alternative, you can write the numbers 1-4 (where 4 is equivalent to the highest level of autonomy) after the tasks in the mind map. Do not forget to add your own categories and subcategories to the matrix if you added them to the goal-based task analysis. Do not consider restrains due to technological, economical, or legal issues. Reflect over the problems that can occur when substituting humans with technology.

Whenever you are finished, we will conduct an interview where you will be able to explain why you have allocated the tasks at the specific autonomous levels.

Goal-based task analysis of DP operations for DPOs

Level of Autonomy					
		1. Decision support	2. Automatic	3. Constrained autonomous	4. Fully autonomous
Task					

Appendix 6 – Semi-structured interview with DPOs

<u>Task analysis</u>

- What is your opinion regarding the task analysis? Covering/lacking/misleading/not representative?
- Did you add or remove anything to it? Why?

<u>Levels of autonomy</u>

- How did you understand the levels of autonomy?

<u>Task allocation</u>

- On which levels of autonomy would you place these tasks?
- There is a difference between feasible and effective task allocation. What do you think would be the most effective allocation of the DP related tasks between automation, an SCC or a DPO?
- Why have you placed the tasks on those levels?
- What is limiting the use of autonomy on SOVs working within wind farms?
- What can be done to overcome those limitations?
- Which problems would occur within a constellation where some or all tasks have been allocated to other parties than a DPO?

<u>The optimal relationship</u>

- What are your general thoughts about using fully autonomous SOVs within wind farms?

Appendix 7 - Consent form

CHALMERS
UNIVERSITY OF TECHNOLOGY

Risks/Discomforts: There should be no risks or discomforts while in this interview.

Benefits: There are no direct benefits for interviewees. However, it is hoped that through your participation, we will learn more about what how the industry best prepares for innovation in autonomous maritime surface vessels.

Confidentiality

All data obtained from you will be kept confidential and will only be reported in an aggregate format (by reporting only combined results and never reporting individual ones). Your responses are anonymized, and **no individual** will be identifiable. Furthermore, it will **not** be possible to identify any individual responses in any analysis or report.

All surveys will be concealed and no one other than the Project PERSONAL DATA PROCESSOR will have access to the data. The data collected will be stored in a secure digital database until it has been deleted. All data will be held on a password protected USB drive, compliant with the requirements of article 28 of the EU General Data Protection Regulation (GDPR, 2016/679) regarding protection for physical persons in the processing of personal data.

Participation

Participation is completely voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your employment status or your standing with your employer. If you desire to withdraw after you have completed this survey, please notify me at this email address: degrell@student.chalmers.se. You do not have to give a reason.

How will my privacy be protected?

Your personal data will be handled in compliance with the EU General Data Protection Regulation and in a manner that does not infringe your personal integrity.

Any information held on a computer or in a database identifying project interviewees will be separated from the data sets and will be destroyed at the end of the data gathering phase during 2019-2023 and will never be passed to your company or any third parties. Following completion of the data gathering phase, contact details will be destroyed.

Questions about the research: If you have questions regarding this study, you may contact Professor Scott MacKinnon   +46 (0) 73 1542592 or email: scottm@chalmers.se

I have read and understood the above consent form and desire of my own free will to participate in this study.

Signature: Print Name: Place and Date:

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Risks/Discomforts: There should be no risks or discomforts while participating in this ethnographic.

Benefits: There are no direct benefits for participants. However, it is hoped that through your participation, we will learn more about what how the industry best prepares for innovation in autonomous maritime surface vessels.

Confidentiality
All data obtained from you will be kept confidential and will only be reported in an aggregate format (by reporting only combined results and never reporting individual ones). Your participation is anonymized, and **no individual** will be identifiable. Furthermore, it will **not** be possible to identify any individuals in any analysis or report.

All surveys will be concealed and no one other than the Project PERSONAL DATA PROCESSOR will have access to the data. The data collected will be stored in a secure digital database until it has been deleted. All data will be held on a password protected USB drive, compliant with the requirements of article 28 of the EU General Data Protection Regulation (GDPR, 2016/679) regarding protection for physical persons in the processing of personal data.

Participation
Participation is completely voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your employment status or your standing with your employer. If you desire to withdraw, please notify me at this email address: degrell@student.chalmers.se. You do not have to give a reason.

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I have read and understood the above consent form and desire of my own free will to participate in this study.

 Signature: Print Name: Place and Date:

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