Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Geoscience and Petroleum

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Human Factor Design of a Control Room for Fleet Management using Underwater Drones in the O&G Industry

Use case scenarios for remote operations of UIDs criticizing functional allocation in IS0 11064

Master's thesis in Engineering and ICT
Supervisor: Vidar Hepsø
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Abstract

Using underwater drones for inspection operations and tasks on subsea facilities has shown to be useful for the oil and gas industry. They are more efficient and safer than human divers, but expensive. Today are the drones connected to a top-site vessel and it is affected by harsh weather and forces, as well as contracts and availability. Placing docking stations on the seabed makes it possible to remove the support vessel and remotely operate the drones from a control room placed onshore, as well as use the docking stations for power supply and data transfer. Placing a fleet of UIDs on the seabed performing inspection operations, working as janitors by looking for anomalies and patterns on the placed equipment/instruments, provides new opportunities for the sector, as well as reduces costs and improve HSE.

Designing a control room for this use is a complex problem. This project, therefore, centers the design around human factors engineering and ISO 11064 - Ergonomic design of control centers, focusing on function allocation between man and/or machine. A performed functional analysis using a qualitative method with 10 conducted interviews, has provided several necessary functions and systems for the control room and its support functions, as well as design specifications. The analysis has also shown that the three use-cases in focus, all have different needs and temporal conditions, along with autonomy, which affects the needed functions/systems, as well as the allocation of the functions between human and/or machine.

The results, in light of ISO 11064-1, show that a dynamic allocation of the functions is needed to get the necessary flexibility and scalability in the system(s). This is because the drones will have different degrees/levels of autonomy when performing the inspection operations and tasks in the three work processes, and the human-machine teaming must be optimized for this. The study also shows that there are difficulties in transferring data from underwater between the drones and the control room and that a priority of which data that is necessary to have in real-time for the control room operator(s) for controlling the fleet safely must be performed. The interviews also show that there are two main structural approaches/concepts when it comes to the structural organization of the control room. They primarily differ in who has the responsibility of the control and/or observation of the drones, as proprietary rooms are a possibility. This also affects the data streams and routing.

With the increased focus on digitalization in the oil and gas industry along with integrated and remote operations, we see that the use of a control room for a fleet of UIDs performing operations at subsea installations will be a good contribution to the needs in the industry. However, it needs further development of technology, especially on autonomy in regard to trusting the drones to operate autonomously. The technology also needs to mature and be robust.

Sammendrag

Bruk av undervannsdroner for inspeksjonsoperasjoner og -oppgaver på subsea anlegg har vist seg å være viktig for olje og gassindustrien. De er mer effektive og tryggere enn menneskelige dykkere, men er kostbare. I dag er droner koblet til et «top site» skip som er påvirket av de harde værforhold og krefter som finnes ute på havet, i tillegg til kontrakter og begrenset tilgjengelighet. Ved å plassere dokkingstasjoner for dronene på havbunnen vil det være mulig å fjerne støtte-båten og fjernstyre dronene fra et kontrollrom som er plassert på land. I tillegg vil dokkingstasjonen fungere som batterikilde for dronen og brukes til dataoverføring. Ved å plassere en flåte med UIDer på havbunnen til å gjennomføre inspeksjonsoppdrag, altså jobbe som vaktmestere ved å se etter ujevnheter og mønstre på det stasjonerte utstyret/instrumentene, vil en åpne for nye muligheter i sektoren, samtidig som en reduserer kostnader og ivaretar HMS.

Design av et kontrollrom for dette behovet er et komplekst problem. Problemstillingen er derfor sentrert rundt menneskelige faktorer og ISO 11064 Ergonomisk design av kontrollsentere, og fokuserer på funksjonsallokering mellom mennesker og maskiner. En funksjonsanalyse er gjennomført ved bruk av en kvalitativ metode hvor en intervjuet 10 stykker. Det har gitt flere nødvendige funksjoner og systemer for kontrollrommet og dets støttespillere, i tillegg til designspesifikasjoner. Analysen har også vist at for de tre ulike inspeksjonsoppdragene er det ulike behov og tidsmessige/timelige forhold for de ulike funksjoner/systemer som en trenger, i tillegg til at tildelingen av dem mellom menneske og maskin varierer basert på oppdrag/oppgaver og autonomi.

Resultatene, i lys av ISO 11064-1, viser at en dynamisk allokering av funksjonene må til for å få den nødvendige fleksibiliteten og skalerbarheten som systemet trenger. Dette er fordi dronene vil ha behov for ulik grad av autonomi når de gjennomfører de ulike inspeksjonsoppdragene og oppgavene i de tre tilfellene, og menneske-maskin-samspillet må være optimalisert for dette. Studien viser også at det er utfordrende å overføre data under vann mellom dronene og kontrollrommet, og at en prioritet av hvilken data som er nødvendig å ha i sanntid for kontrollromsoperatøren(e) som styrer flåten med droner, er viktig med tanke på sikkerheten. Intervjuene viser også at det er to strukturelle konsepter som er mulige når det gjelder den strukturelle organiseringen av kontrollrommet. Det som skiller de to typene er hvem som skal ha ansvar for kontroll/styring av dronene og/eller observasjon, ettersom proprietære kontrollrom er en mulighet. Dette påvirker også data-tilførselen og rutingen.

Med det økte fokuset på digitalisering i olje og gass-industrien har sammen med integrerte og fjernstyrte operasjoner, ser vi at bruken av et kontrollrom for flåtestyring av UIDer som utfører inspeksjonsoperasjoner på subsea-installasjoner vil være et godt bidrag til behovene i bransjen. Derimot så trenges det mer (videre)utvikling av teknologien, spesielt på autonomi i forbindelse med å gi systemet nok tillit for å kunne opererer autonomt. Teknologien trenger også å modnes og være robust nok.

Preface

This report is the result of the course TPG4920 - Petroleum Engineering, Master Thesis at Norwegian University of Science and Technology (NTNU) by Ingrid Folstad. The master thesis was written during the spring of 2021 as a part of the 5-years master program in Engineering and ICT (I&IKT), with specialization in ICT and Petroleum, at the faculty of engineering (IV). The master focuses on the design of a control room for three inspection operations performed by a fleet of underwater drones (UIDs) in the oil and gas (O&G) sector. As a basis for the thesis were a specialization project on sensor platforms and capability stack modeling in the petroleum industry conducted during the fall semester of 2020.

It is an advantage to have a general understanding of subsea systems and/or the oil and gas industry when reading this thesis. Knowledge about human factors, ISO 11064, and underwater drones is also an advantage.

I would like to extend a thank you to my supervisor Vidar Hepsø (Professor 2, NTNU/Equinor) for guidance and feedback on the thesis work. Further, I would also like to thank the interview objects for the time they used to participate in the study with their experiences, feedback, and visions. Lastly, I send a huge thanks to good friends and fellow students for good discussions and conversations around the problem statement and thesis work, and for the extra motivation.

Trondheim, June 10, 2021

Ingrid Folstad

Ingrid Folstad

Nomenclature

The following table lists some of the abbreviations and nomenclature used in this thesis:

Abbreviation	**Description**
AI	Artificial Intelligence
AR	Augmented Reality
AUV	Autonomous Underwater Vehicle
e.g.	*exempli gratia*: for example.
CAQDAS	computer-assisted qualitative data analysis
HABA-MABA	Humans are better at - machines are better at
HMI	Human-machine interface
HMT	Human-machine teaming
HSE	Health, Safety, and Environment
I(C)T	Information (and Communication) Technology
i.a	*inter alia*, among other things...
i.e.	*id est*: that is, in other words...
IEM	Integrated Environmental Monitoring
IMR	Inspection, Maintenance and Repair
IO	Integrated Operations
ISO	International Organization for Standardization
LoA	Level of Autonomy
ML	Machine Learning
NCS	Norwegian Continental Shelf
NSD	Norwegian centre for research data
NTNU	Norwegian University of Science and Technology
O&G	Oil and Gas
ROV	Remotely Operated Vehicle
SA	Situational awareness
SDP	Subsea Docking Plate
SDS	Subsea Docking Station
Sonar	SOund Navigation And Ranging
UID	Underwater Intervention Drone
VR	Virtual Reality

Terms and concepts of importance:

ISO 11064	A international standard from British Standards Institution that focuses on Ergonomic design of control centres. ISO 11064-1 is used as a base for this thesis. The standard consists of 7 parts.
Sensor platform	A drone, docking station, stationary ocean observatory, etc. that collects data using sensors.
Capability stack model/platform	A model based on the principles of integrated operations that take into account the capabilities needed to design a system.
Fleet management	Controlling multiple assets at the same time.
Human factors/ergonomics	Engineering discipline that focuses on designing systems for humans, and not systems that humans must adapt to.
Industry 4.0	The fourth industrial revolution focusing on digitalization and automatizing of the industry. Uses advanced technology and includes among others Big data, Internet of Things (IoT), and cloud storage services. OPC UA and RAMI 4.0 are some frameworks that are developed according to the needs of Industry 4.0.

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Chapter 1

Introduction

The use of drones in the oil and gas (O&G) industry has evolved ever since BP first started piloting the use of drones in oilfields in Alaska in 2006 (Murray, 2020). Using drones on onshore and offshore installations, typically for inspection operations, have many benefits. These are among others reduced costs, improved safety, reduced downtime, and access to areas that humans cannot reach or is too dangerous for humans to enter. The use of drones in O&G is can be seen as especially useful in the offshore environment, as it is affected by harsh weather and forces, as well as much equipment is placed at the seabed or underwater. The use and development of drone technology in this area are therefore seen as valuable.

Looking at the North Sea and the Norwegian Continental Shelf (NCS), and other offshore environments, we see that it is characterized by harsh weather and forces which makes operations tough and demanding. Placing different types of drones in this environment will reduce human risks as well as makes it possible to do inspections, monitoring, maintenance, and repair on the facilities more efficient, less costly, and much safer for the workers involved.

The petroleum sector is currently in a digital revolution, affected by the need for digital transformation. To handle this big change, one often refers to the term *Integrated Operations(IO)*, which is the integration of people, work process, and technology to make smarter decisions and better execution, and is a method for better utilization of the development potential in the oil and gas industry. Together with remote operations does it include remote control and monitoring of fields and/or platforms, which is something that has been done in O&G for a good while now, but with the increased development in technology is only advancing. However, there is a need for more advanced functions and systems for making this possible, as well as following the strict legislation's that the sector is facing. The development of underwater drones is one part of this digital journey, which will only become more important in the future.

The technology when it comes to underwater intervention drones (UIDs) is improving, and the use of ROVs and AUVs has become a necessity for performing inspections on offshore facilities. However, they are currently controlled from a support vessel at the site (as seen in Figure 1.1), which offers some challenges and large costs to the operations. With further development on autonomy can autonomous operations be seen as safe(er), and the vessel can be replaced by a control room that can remotely operate the drones from shore. Together with docking stations, placing the drones (permanently) on the seabed, will this be a great use of technology and provide new opportunities. A possibility here is fleet management of the drones, meaning that one does not only control one drone but a fleet of drones at the same time. This is where this thesis comes in.

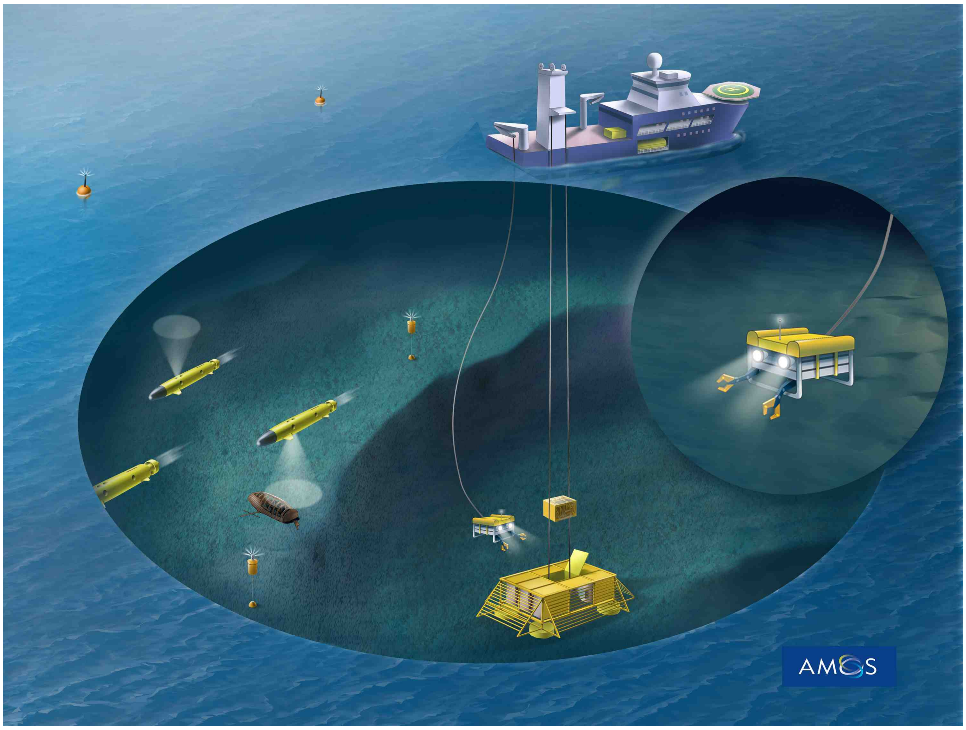

Figure 1.1: Illustration of operations performed underwater with a top-site vessel (NTNU AMOS)

1.1 Case description

Controlling a stationed UID fleet from an onshore control room will reduce costs and ensure safety when performing regulatory controls, monitoring, and inspections on subsea facilities placed on the seabed, such as pipelines and wells. In this thesis is the case centered around fleet management of underwater drones in the O&G-industry. The fleet consisting of different types of drones from different suppliers that are placed/docked at the seabed. The UIDs are controlled from a remote control room placed onshore and are performing three types of operations: fixed continuous monitoring, check/control and report, and planned inspection on the subsea facilities.

As there does not exist such a control room today in O&G, the thesis will focus on how to design a control room for this purpose in the early phase of development defining its necessary functions and structure. It will not go into the details on how to physically design the room(s) with the recommended number of screens and types of tables and chairs, or which systems and programs should be used, but present different models for organization and how data should be routed in these models. To gather data on how to develop such a room, a function/system analysis is performed with a qualitative method in order to detect the (special) needs for the people, organizations, and companies involved.

The functional analysis, in this case, is centered around three main areas. One of them is function allocation between humans and machines, and integration between them both, as different task demands for different handling, and machines and humans have different performance characteristics. This is especially relevant in this case, as the drones can operate on different levels of autonomy (LoA), taking over some of the "traditional" human tasks such as control and management of the drones. The teaming of machines and humans must be balanced and optimized, while at the same time utilize the strengths of each individual. Secondly, will a UID-control room require a lot of collaboration (*samhandling*[1]), internally and externally (with other companies, operators, and/or suppliers). An important part of this case is therefore to look at how this collaboration should be managed and which tools are needed (virtual and physical) for them to make good decisions together. It may also be relevant to look at the connection to other control centers/rooms performing other tasks. Lastly, the analysis focuses on data sharing, processing, and handling. The sensor platforms collect a large amount of data that needs to be processed and managed. All data are not necessary/useful for the control room operators (CROs) controlling the fleet, but might be for other departments and support functions, e.g.for they planning inspections. The need for information and data will vary for the different stakeholders and users, and there must be a system for how to distribute the data to the right source.

This control room will control a fleet of UIDs and not a facility/plant, which is what control rooms in O&G have primarily been used for until this moment. The development of such a control room is a highly relevant issue and it is needed in the O&G-industry, as well as other industries that are using drones/robots to perform inspection and monitoring tasks of its constructions. However, from the specialization project [2], we see that managing this type of operation has a high degree of complexity. The capability stack model is therefore a good tool for methodically divide the case into smaller parts, as well as focus on the whole. The stack will therefore form the basis of this thesis.

Assumptions:
Some assumptions have been made in this thesis, and these are mostly about narrowing down the complexity of the problem statement. For this case, it is assumed that the drones and docking stations' cybernetic control systems are in place. It is also assumed that all hardware, with its following software, is fully operable. When it yields for the docking station/plate, it is assumed that all suppliers are using the "universal" docking plate developed by Blue Logic with support by Equinor [3]. This gives some infrastructural benefits and simplifications as all drones can use the same dock and form it potentially cover a larger area. Otherwise, it is assumed that the necessary infrastructure for this control room and its subsea equipment is in place. This is e.g. fiber optic cables, network, power, screens, etc. For fleet management, it is assumed that the drones can operate together with or without cable to the docking station.

1.2 Objective and Problem Statement

The objective of this master's thesis is to analyze the chosen case with a focus on human factor engineering (HFE)/ergonomics. This yields especially for the technical parts, functions, that need to be developed for this control room to be operable.

Based on the objective, the following problem statement is presented:

[1]The term "samhandling" has a higher relative ambition level than the corresponding processes covered by the expressions "collaboration", "cooperation" and "coordination", as described by (Torgersen and Steiro, 2018)

[2]The specialization project was delivered during the fall semester of 2020. The project did was mainly about understanding the capability stack model, and therefore focused on sensor platforms and sensors that could be placed on the platforms, as well as data streams. It was called "Capability Stack Modeling of Sensor Platforms in the Petroleum Industry - Remote Operations of Autonomous Underwater Vehicle and Docking Station."

[3]More information on the docking station/plate: https://www.bluelogic.no/news-and-media/subsea-docking-station-sds-

How to develop/design a control room for operations performed by a fleet of underwater drones (UIDs) in the petroleum industry?

To narrow down the problem statement even further, the following research questions will be addressed:

RQ1. Which functions/systems are necessary in the control room, especially aimed at machines and humans?

RQ2. How to handle the data and information flows, especially aimed at the drones' work processes?

RQ3. How to facilitate good cooperation (*samhandling*) between the various parties involved in the operations?

Notice that this thesis focuses on the design in an early part of the development.

1.3 Goal

One of the core issues with this type of UID-control room is how one has to compensate for the situational awareness that the humans have and the drones/machines do not, as autonomy is an important factor for making it possible to manage a fleet of UIDs performing these three inspection operations. Today's technology is immature (*umoden*) and must be perceived as trustworthy, as well as being safe. One of the main goals with this thesis is therefore to perform a functional analysis and present a development plan for this given case, based on the developed data, existing literature, and assumptions around future developments on soft- and hardware. The plan was supposed to be a staircase model, starting with the basics and moving up step by step as capabilities are defined, integrating and combining elements/resources. As the thesis took form and the problem case evolved, was it no longer possible to present the plan as planned. This will be seen in section 4.3.

1.4 Approach

The problem statement in this thesis is in an exploring area. To be able to deliver on the objective, there will be performed a qualitative research analysis, which in this case includes a literature review and interviews with central people in the academia/business world.

An interview guide will be developed based primarily on these three documents:

- ISO 11064 - an international standard for the ergonomic design of control centres, especially focusing on part 1: Principles for the design of control centres,
- EEMUA 201 - a guide on control room specification, design, commissioning and operation, and
- the results and findings of the author's specialization project delivered in December 2020.

The results from the interviews will be transcribed and analyzed/coded before being presented and discussed later in this thesis.

1.5 Existing solutions

Control rooms have been used for decades for controlling production in factories and monitoring operations. They can be found in several industries, such as in nuclear power plants, chemical plants, space, and the petroleum industry. There also exist control rooms for fleet control, especially in air traffic control and satellite surveillance, but not for underwater drones. They are used for controlling and managing multiple assets, such as planes and satellites, to ensure safety and organize and expedite the flow of assets. The fleet they control does also has some degree of autonomy, which is also a common factor with this UID-control room.

When it yields for IMR-operations on subsea facilities, they are today primarily executed by Remotely Operated Vehicles (ROVs), or Autonomous Underwater Vehicles (AUVs) in some cases, and require support from an offshore vessel, ROV systems, tools, and experienced ROV-operators (Schjølberg et al., 2016). The efficiency of the operations is highly dependent on the experience of the operator, as the ROV is manually controlled, and the availability on ships and weather conditions. Vessels available in the spot market operate on-demand and this may increase the price and time of operation. Other vessels operate on more long-term contracts and are available on shorter notice (Schjølberg and Utne, 2015). Removing the vessel and remotely operate the ROV/AUV for IMR-work will give a lot of benefits, such as reducing time spent on planning and execution of the mission, as well as reduce or prevent downtime on the subsea facility, which all will reduce the total cost and increase efficiency (Schjølberg et al., 2016).

Introducing autonomy to underwater drones is a complex problem, as one has to ensure that the drone can do no harm to people and equipment - that it does not pose a risk. The use of autonomy on underwater drones today is little and on a low level: the drones can move around autonomously, but they are closely monitored. When it comes to performing operations autonomously is this something an operator must fully control and observe, as the risk for damage(s) is too high at this point. However, if one takes a look at the car industry, for example, one can see that cars are becoming more and more self-driving and given enough trust to be on the road along with other vehicles, but it still remains much work in this field. Still, this technology is something that this type of control room should utilize.

When it yields for formation control of the UIDs, especially AUVs, it is an area still lacking (some) experimental results and practices, having only pure theoretical research (Buadu and Schjølberg, 2018). However, it is, according to Das, Subudhi and Pati, 2016, an emerging research topic in robotics. Formation control is important when having a fleet of underwater drones, but it presents several challenges when having multiple AUVs/assets. These are classified as wave disturbance, communication constraints, collision, and obstacle and might be affecting trajectory tracking, path following, formation shape generation, switching between shapes, and path generation for multiple AUVs (Das, Subudhi and Pati, 2016). This is however something that is assumed that is in place in this thesis.

In France, at the University of Bordeaux, they have started a Ph.D. project which aims to create a new generation of unmanned platforms, looking at *Operations room design for the control of a fleet of robots*. They intend to design a human-centered design-based operations room to manage the fleet of robots, but also establish the cooperation rules among the different agents (Rolos, Boy and Masson, 2019). They have only published the mentioned article, and no contact with them has been tried established.

1.6 Structure of the Thesis

The report is divided into six chapters, including this introductory chapter. The rest of the five chapters in addition to appendices are structured as follows:

Chapter 2: Background Basis
The chapter discusses relevant theories, models, and definitions that build a foundation for the thesis' case. It provides the reader with the necessary information needed to better understand the topics addressed. The chapter introduces three topics: Integrated Operations (IO) in the petroleum industry, Human Factor Engineering (HFE), and Underwater robotics and autonomous vehicles.

Chapter 3: Method
The chapter will provide the reader with a description of the used methodical approach in this study - a qualitative research method using interviews, and how it is implemented. It also touches on limitations, evaluation, and criticism of the method.

Chapter 4: Results and Analysis
This chapter presents the main results of the thesis with some analyzes, focusing primarily on human factors. In this chapter is also the three inspection work processes that are the study's use-cases presented with its temporal conditions. It also contains the results from the functional analysis along with two alternatively concepts for organizational structure.

Chapter 5: Discussion
In this chapter is the major findings presented from results further discussed, and the empirical findings are linked to the theory presented in chapter 2.

Chapter 6: Conclusion and further work
The main conclusion from the work is presented in this chapter. Further work is also highlighted.

Appendices
The appendix section contains documentation that is (might) relevant for the reader. These documents are related to the methodical approach, containing the information letter sent out to relevant interview objects (in both English and Norwegian) and permission from NSD to run the study. It also has a copy of the consent form handed out to the participants and the interview guide in Norwegian (as the interviews were only conducted in Norwegian).

Chapter 2

Theory Basis

The intention of this chapter is to provide the reader with the necessary background information and basic concepts that form the foundation of the thesis work.

The theory basis chapter is divided into three main topics:

- Integrated Operations (IO) and remote operations: gives an overview of what integrated operations and remote operations in O&G are, and presents the capability stack model that is used as a basis in this thesis. Digital transformation in the sector is also a relevant theme that is introduced.
- Human Factors Engineering (HFE) of control rooms: explains what human factor engineering and control rooms are, as well as how the two are connected.
- Underwater robotics and autonomous vehicles: provides information about the underwater drones/sensor platforms in focus, as well as autonomy and automation. It also discusses function allocation between humans and machines, which is a red thread in the thesis.

The three topics are all linked to the UID-control room in some way, and the control room is what binds them all together. Integrated and remote operations give an overview of how it is to operate both offshore (the UIDs) and onshore (the control room), in regards to people, technology, and organization. The control room should be designed ergonomically, according to the principles in human factor engineering. And lastly, should the functions the control room executes be allocated between man and machine, as there are autonomy and automation included in the picture.

2.1 Integrated Operations

New and powerful information and communication technology (ICT) are key factors for the undergoing transition making profound changes in the oil and gas industry as it affects the traditional work processes and organizational structures (Lilleng and Sagatun, 2010; Steiro and Torgersen, 2013). With efficiency as an important contributor have new approaches been used to overcome traditional obstacles using the new technology that has enabled new forms of interaction and collaboration in offshore operations (Steiro and Torgersen, 2013). This new way of working (Table 2.1), is called Integrated Operations (IO) and has been gradually introduced to petroleum companies located at the NCS.

Table 2.1: IO and new ways of working in petroleum companies (Steiro and Torgersen, 2013)

Traditional way of working	Integrated Operations way of working
Serial	Parallel
Single discipline	Multi-discipline
Dependence of physical location	Independence of physical location
Decisions are made based in historical data	Decisions are made based on real-time data
Reactive	Proactive

IO is a structural top-down approaching operational concept used to tie teams and organizations together through the use of appropriate visualization technologies, design of physical workspaces, design of workflows, and cultural adaptation, with the means to facilitate interaction and teamwork, (BRU, 2016). The term IO has many definitions, but Lilleng and Sagatun (2010) have defined IO as: "the integration of people, processes, and technology to make and execute better decisions quicker. IO is enabled by the use of real-time data, collaborative technologies, and multidiscipline workflows (ways of working) in work processes.", resulting in global access to real-time information, collaborative technology, and integration of multiple expertise across disciplines, organizations, and geographical locations (IO center, 2021).

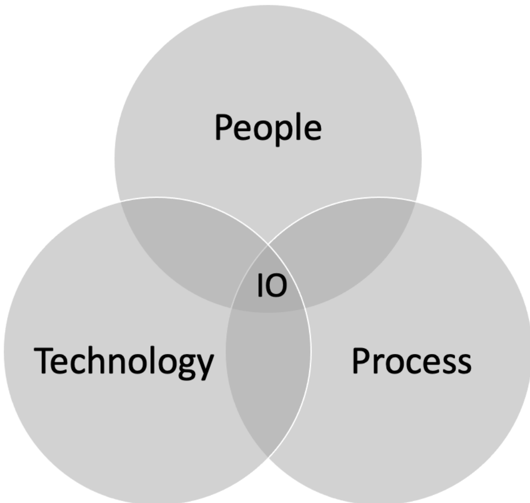

Figure 2.1: Illustration of how people, technology and processes are integrated in Integrated Operations (IO).

One of the key components related to IO is the establishment of onshore support centers as tasks, functions, and people are moved from offshore platforms to land (Rosendahl and Hepsø, 2013). This is a result of the new technology making it possible to bring real-time data from sensors and other equipment placed on the process plant/subsea facility from the offshore installations to land (Gressgård et al., 2018). Access to real-time data has made it possible to move to a (near) real-time way of working and opened up for a connection of one or more sites or teams working together, as well as a more multidisciplinary way of working (Skjerve et al., 2013).

Technical collaboration tools are extremely important in IO as one has to communicate and collaborate with people on land and offshore, as well as with other companies or departments. IO collaboration technology, therefore, consists of high-quality video conferencing, shared workspaces, and data sharing facilities. These arenas include so-called collaboration rooms (operation rooms) for rapid responses and decision-making, as well as walls/screens to share information. This makes it possible to involve all parts in a discussion/decision making, either they are onshore or offshore (Steiro and Torgersen, 2013). As a result, we see that companies tend to involve increased outsourcing of work to contractors and other third parties, as well as closer integration between operator and contractor tasks (Skjerve et al., 2013).

The achievement of faster and better decisions is important in IO, as it intends to enhance the experience of integration and common understanding between the onshore and offshore organizations, as well as personnel both offshore and onshore have in-depth knowledge about the situations and challenges that arise (Steiro and Torgersen, 2013). To be able to make better decisions more quickly have Lilleng and Sagatun (2010) presented a stack model consisting of seven interdependent success criteria presented in a pyramid layered model seen in Figure 2.2. These criteria represent the necessary and sufficient conditions for value creation utilizing IO and make up a man, technology, and organization (MTO) perspective of enabling factors Together the seven success criteria create capabilities for faster and better decision and execution that add significant value to the business (Lilleng and Sagatun, 2010).

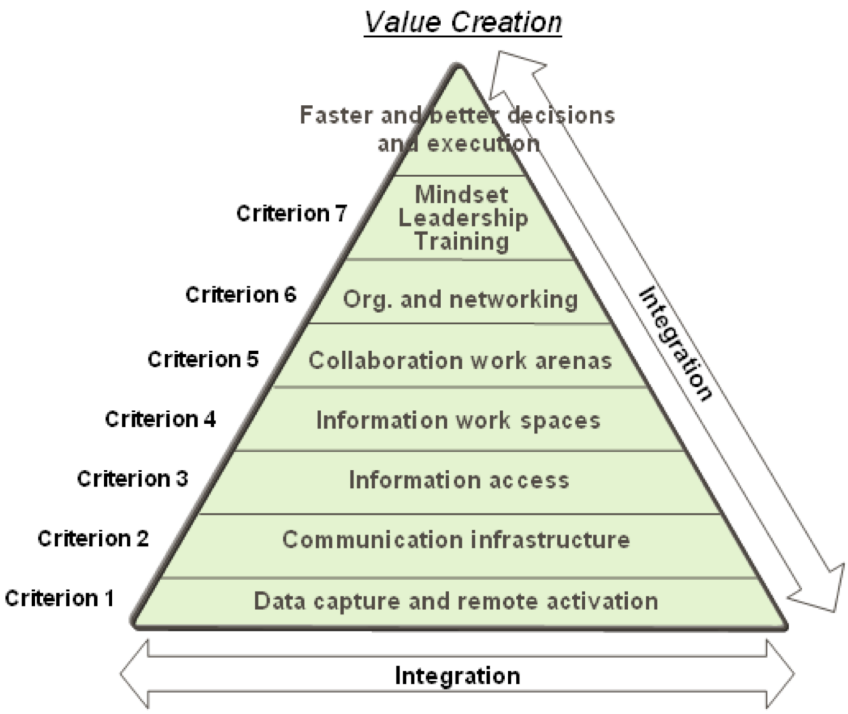

Figure 2.2: IO drivers and success criteria (Lilleng and Sagatun, 2010).

2.1.1 Capability Stack model

In integrated operations is creating capabilities an important factor for obtaining better decisions more quickly. A capability is defined as a "combined capacity and ability to plan in accordance with our business objectives through a designed combination of human skills, work processes, organizational change and technology", and the development of capabilities is a performance improvement methodology (Larsen et al., 2012). Capabilities are not static and Henderson, Hepsø and Mydland (2013) that presents a capability platform concept. Here they address the importance of having a capability approach in IO and how it can improve our understanding of the four key elements people, process, technology, and governance (Table 2.2), as well as how the four are connected and managed to create a scalable and sustainable practice that creates value.

Table 2.2: Influencing factors within different aspects of the system (Henderson, Hepsø and Mydland, 2013; Hepsø et al., 2012)

Technology	Hardware equipment, facilities, communication and automation systems, software and data
Process	Business processes - workflow, roles and responsibilities and collaboration principles
People/resources	Skills, competence, experience, leadership and all other soft people issues associated making things work
Governance/ organization	Decision rights (positions), location of resources, business structure, internal/external sourcing, contracts, agreements, rules and regulations

Creating a capability stack model that consists of a set of capabilities deployed by multiple parties, is a way of decoupling the complexity of the system as it introduces distinct layered activities connected by standard interfaces. The stack model is a way of connecting the organization to the concept, as the key idea to achieve this is by introducing layers and principles for communication in-between the layers. Through this layering, one can thus create efficiency, flexibility, create economic value, and have explicit architectural control points (Henderson, Hepsø and Mydland, 2013).

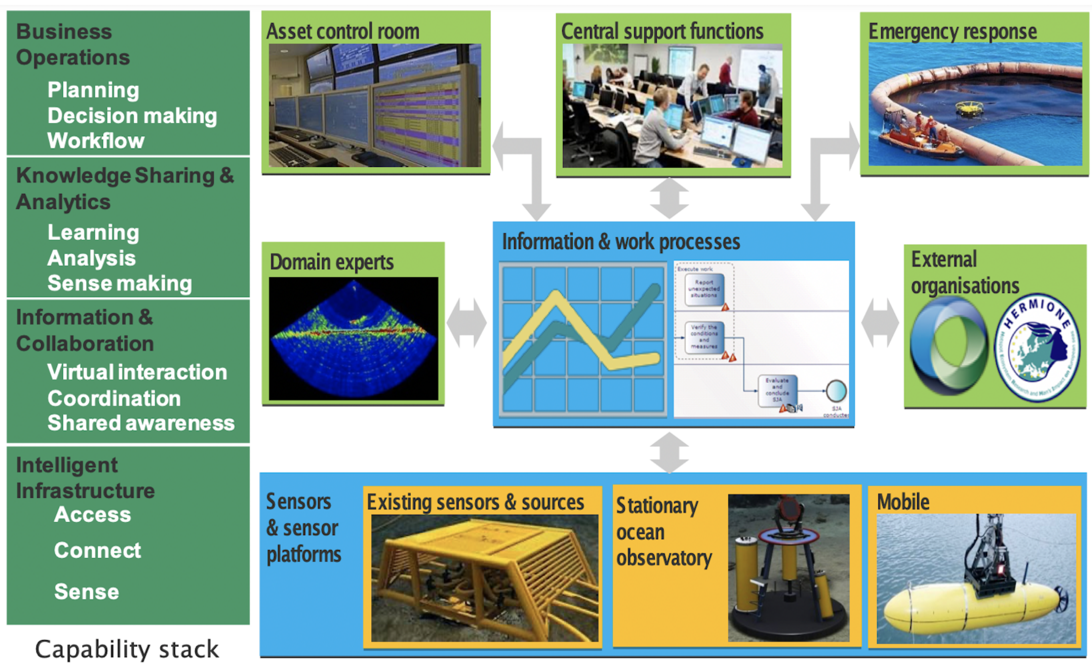

Figure 2.3: Graphical visualization of a capability stack, with the technology resource layer at the bottom (Hepsø et al., 2012).

The stack model presented in Henderson, Hepsø and Mydland, 2013 (and illustrated in Figure 2.3) consists of five layers or niches presented inTable 2.3, and are based on the Enterprise Architecture

Framework (EAF). It is dominated by the technology layer placed at the lowest level, but for it to work, all layers must be included. Enterprise architecture is defined by sets of activity units and describes the business process of IT by creating a relationship between the IT structure that is used in the organization and each system (Jin-Woo Kim et al., 2005). The model is structured into layers/domains which allows for systemic design decisions on all system components and making long-term decisions around new design requirements, sustainability, and support (wikipedia, 2021). The architecture's four domains: business, data, applications, and technology architecture, can be regarded as five layers: environmental, business layer, data layer, information system layer, and technology layer, where the idea is that each layer contains components that execute processes and offers services to the layers above (wikipedia, 2021). This can be seen in the capability stack model as well.

Table 2.3: The five basic niches/layers in a capability stack (Henderson, Hepsø and Mydland, 2013)

Technology resource layer	Comprises capabilities to deploy and operate the basic technology and equipment needed (mainly components made out of steel). Does no include sensors and ICT-capabilities.
Intelligent infrastructure	Enables increasing automatic monitoring due to sensing capabilities. Needs the technology resource layer, since in most cases it is hard-wired into the technology layer.
Information and collaboration	A safe and reliable data communications and infrastructure is needed to automatically collect sensor data
Knowledge- sharing and analytics	Enables real-time processing and analysis that is increasingly required for effective operations of an instrumented field.
Business operations	Addresses the development and execution of work processes and decision support to enable the realization of performance.

Lilleng and Sagatun (2010) success criteria can be used during the process of defining capabilities both within and across the layers in the stack, as the stack model represents the necessary and sufficient conditions for effective value creation by IO (see Table 2.4).

Table 2.4: The relationship between the seven IO criteria from Lilleng and Sagatun and the capability stack

IO-criteria	**Capability model**
1. Data capture, and remote activation 2. Communication infrastructure, data transmission and standards 3. Information access	Foundational capabilities: Technology resources, Intelligent infrastructure, Information and communication
4. Information visualization and work spaces 5. Collaboration work arenas	Analytics and collaboration capabilities
6. Organization, networking and work process framework 7. Mindset, leadership and training	Business operational capabilities

2.2 Digital transformation in the Petroleum Industry

Digitalization is the digital transformation facing the society and economy today, and digitalization and smarter use of data is an increasing top priority among today's O&G companies, and we see that the industry changes as a result of this priority (BRU, 2016; Gressgård et al., 2018). Factors contributing to the focus on digitization in recent years are the scope of opportunities that new technology has provided combined with an enlightening focus on cost and efficiency in the sector. This includes i.a. further development of integrated operations, remote control and operations, automation and robot technology, artificial intelligence (AI), sensor networks, analytics software, and computing power (Gressgård et al., 2018).

Burkett (2017) refers to digital transformation as the impact caused by the process of digitalization, where digitalization is the process of leveraging digitization (changing data from a physical to a digital format that can be read/processed by a computer) to improve business processes. For the petroleum industry is this digital transformation possible with new technology, introducing new methods and tools. Work processes are becoming more efficient as many tasks are automated and/or replaced by machines, and gives better data basis for analysis and decision-making. This transition has also shown great ripple effects to HSE and contributed to greater competitiveness (Gressgård et al., 2018).

In *Digitalisering av petroleumsnæringen* are Gressgård et al. (2018) pointing to four initiatives when it comes to digitalization in the sector: Robots and autonomous vehicles, Integrated operations, Automation of drilling operations, and The digital oilfield, where the first two are central in this thesis. The report also states that digitalization in O&G first of all is about the development and use of digital tools and processes for improving decisions, collaboration (*samhandling*), and automation - which overall a further development of IO.

2.3 Remote Operations and Control Rooms

Monitoring and controlling operations remotely is something that has been performed in the O&G industry for decades as it removes the geographical location and physical distance in oilfield service delivery, as well as reduces the cost of delivering services, increases geographic reach, and improves safety (Saeverhagen et al., 2013). With new technological improvements and tasks moved onshore, along with improved communication infrastructure between onshore and offshore sites, has remote functions, such as remote control and remote monitoring, become more advanced, with remote operations (IOGP, 2018).

Remote operations are about doing work at a distance, and Saeverhagen et al. (2013) points to remote operations in O&G as: "...real-time workflows which integrate the activities of personnel at rig sites, assembly, and maintenance and overhaul (AMO) facilities, with remote operations centers (ROC) or operator real-time operational centers (RTOCs) anywhere in the world.". It is mainly a matter of acquiring sensor data from equipment and instruments that are located subsea/offshore, and transferring, as well as processing, these at an external location - in a remote operations center. The remote operations center or room is located outside the production site boundary in a safe zone, as seen in Figure 2.4. The room is a core function entity and has stationed operators (CROs) that carry out centralized control, monitoring, and administrative responsibilities (British Standards Institution, 2001a). The room is staffed around the clock, 24/7, so that it is possible for the CROs to monitor and assist an ongoing operation(s) all hours of the day.

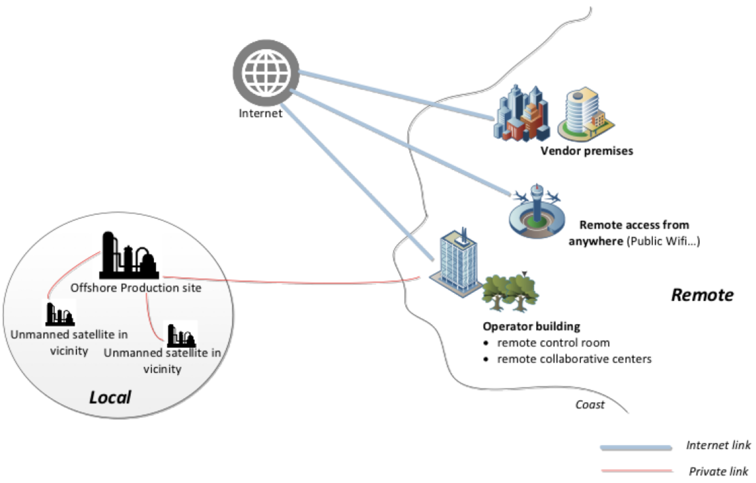

Figure 2.4: Example of local vs. remote (IOGP, 2018)

In a remote operation does remote control refer to doing actions such as control commands, setpoint changes, and operation monitoring on detailed graphical displays at a distance, where the range of remote functions will be project dependent, from full operation to specific and ad-hoc remote support (IOGP, 2018). It is the technical realization.

A remote operation, however, is an operating concept along with IO. This meaning that it handles all the technical aspects and focuses on how to get the interaction between all involved parties in the operation such as man, technology, and organization (Table 2.2). It comprises the technology where a master controls a slave from a distance. In O&G operations is the master typically a human operator stationed at a control room/center, and the slave is typically a remote robot (UID), oil platform, or ship. The operator is in full control of the system, but the system can be given a level of autonomy (LoA) using automation technology (further explained in section 2.5), replacing the human operator in some tasks/situations.

Remote operations builds on IO and its concepts, and is an important topic in this thesis. The problem case in this study, with the UID-control room, differs slightly from previous control rooms as it has several units. Normally, there would be one plant per control room, but here we are talking about having multiple fields or many (mobile) units that one controls from the same location (or from proprietary locations) onshore.

With the increasing digitalization in the sector has more activities been digitized and facilities are becoming unmanned and placed at the seabed, making huge potential in onshore control rooms, especially when it comes to HSE, economics, environmental footprint, and efficiency. To observe and control these installations and/or the environment where they are placed, and to supervise and control operations in the area, are onshore control rooms needed along with underwater vehicles performing the necessary tasks in the operation.

In the capability stack (Figure 2.3) is the control room (or center) placed on top in the business operations layer, as its role is to ensure workflow, make decisions based on given information (from lower layers in the stack), and plans operations. The room is necessary for combining the different levels and parts of the mission together, as it has access to data and information streams, analysis tools, and other central support functions necessary for making decisions and survey the installation. It is also a place for collaboration and management between different fields relevant to the operation. Remote control is especially important when using autonomous robots, and the remote-control room provides the necessary functions needed.

2.4 Human Factors Engineering (HFE)

Human factors engineering (HFE), also called ergonomics or human engineering, is a scientific discipline that applies systematic methods and knowledge about people's physical and psychological characteristics to evaluate and improve the interaction between individuals, technology, and organization (Chapains and Holstein, 1999; Johnsen et al., 2011). It is a collection of data and principles about human characteristics, capabilities, and limitations in relation to machines, jobs, and environments - it is about what makes technology work for people (Chapains and Holstein, 1999; Lee et al., 2017).

Lee et al. (2017) defines HFE as: "a discipline that considers the cognitive, physical, and organizational influences on human behavior to improve human interaction with products and processes.". HFE aims to create a working environment that contributes to achieving healthy, effective, and safe operations, by optimizing the human contribution, minimize the risk for design-induced stress to health and personnel, or process safety or environmental performance. To do so, an interdisciplinary team has to be formed to ensure systematic end-user participation, by conducting human factors analyses such as function and task analysis (Energy Institute, 2020; Johnsen et al., 2011).

The overriding principle in HFE is making a human centered design (HCD), an approach centering the design process around people. The goal is to find a system design that supports the users' needs and is compatible with their abilities, rather than designing a system to which the users must adapt - *"If a system does not work for people, it does not work"* (Lee et al., 2017). In ISO 11064-1 is an HCD approach further explained as: "...the combination of humans and machines, in its organizational and environmental context, is considered as an overall system to be optimized. This optimization is achieved by developing solutions that emphasize and maximize the strengths, features, and capabilities of both humans and machines in a complementary fashion." (British Standards Institution, 2001a). The four elements, as seen in Figure 2.6, must harmoniously be integrated during all phases of the design process, and into the traditional function-orientated design approach.

Another important key principle in HFE is to improve design through iteration (as also seen in Figure 2.6) (Johnsen et al., 2011). Combined are these principles central for the understanding and meeting of people's needs, as one has to understand the users, create a prototype based on these needs, and then evaluate iteratively (Figure 2.5).

Other foundational principles in HFE are presented by IEA (2020) in *"Principles and Guidelines for Human Factors/Ergonomics (HF/E) Design and Management of Work Systems"* (IEA, 2020):

Principle 1. Ensure worker safety, health, and well-being in the optimization of work systems as a top priority;

Principle 2. Design and manage work systems to ensure organizationally and worker alignment, continuous evaluation and learning, and sustainability;

Principle 3. Create a safe, healthy, and sustainable work environment from a holistic perspective, understanding and providing for human needs;

Principle 4. Account for individual differences and organizational contingencies in the design of work systems;

Principle 5. Make use of collective, trans-disciplinary knowledge and full participation of workers for designing systems, detecting problems, and creating solutions for HF/E in work systems.

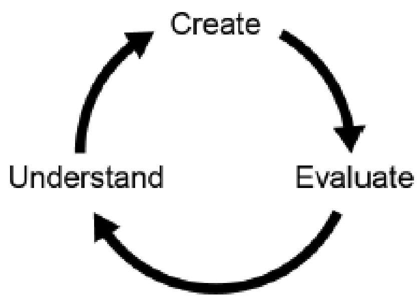

Figure 2.5: Human factor engineering design cycle (Lee et al., 2017)

2.4.1 Control room & HFE

Building a control room is a complex project. A control room involves multiple people from different disciplines and they all have different needs. HFE is therefore important in the design of a control room to ensure that the human is taken care of. There exist some standards and/or documents that ensure that human factors are taken into account and that the design is centered around humans.

As mentioned in chapter 1 is this thesis built primarily around three documents, where two of them are related to HFE and control room design. The two are presented below.

ISO 11064 - Ergonomic design of control centres

The International Organization for Standardization (ISO) has developed a number of standards carried out from technical committees that numerous countries are bound to implement, including Norway. ISO 11064 deals with the ergonomic design of control centers and presents requirements and recommendations relating to ergonomic and human factors in designing and evaluating control centers with the view to eliminating or minimizing the potential for human errors (British Standards Institution, 2001a).

Designing and developing a control center is a complex task that should not be developed separately from the objective and goals, and ISO 11064 is a tool for helping through this process by performing a diversity of analysis and design activities. As seen in Figure 2.6, the standard has a human-centered design approach, taking to account the interaction between humans, machines (soft- and hardware), work environments, and control (operation and management).

The standard is intended used by multiple industries, such as air traffic control operations, electric power generation, and offshore operations. This makes it generic, and it, therefore, does not go into details on industry-specific requirements

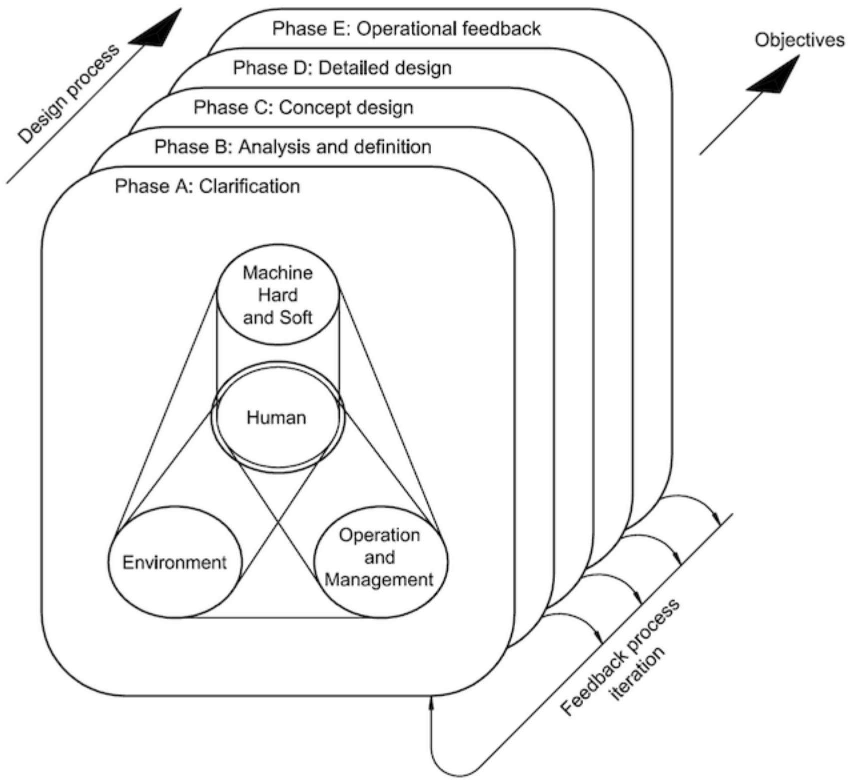

Figure 2.6: Ergonomic approach to system designs (British Standards Institution, 2001a)

ISO 11064 consists of seven parts, each summarized below:

- **Part 1: Principles for the design of control centres**
  This part presents nine principles that should be taken into consideration for the ergonomic design of control centres:
  - Apply a human-centered approach
  - Integrate ergonomics to engineering practice
  - Improve design through iteration
  - Conduct situational analysis
  - Conduct task analysis
  - Design error-tolerant systems
  - Ensure user participation
  - Form an interdisciplinary design team
  - Document ergonomic design basis

  Which can be divided into five main phases, as seen in Figure 2.6. (British Standards Institution, 2001a).

- **Part 2: Principles for the arrangement of control suites**
  This part covers the ergonomic design principles, more specifically the various arrangements of room and spaces in a control suite. The principles presented are based on analysis of functions and tasks that have to be supported by the control room and functionally related rooms (British Standards Institution, 2001b)

- **Part 3: Control room layout**
  Establishes the ergonomic principles for the layout of the control rooms (British Standards Institution, 2000).

- **Part 4: Layout and dimensions of workstations**
  Establishes the ergonomic requirements, recommendations, and guidelines for the design of workplaces in control centers. It covers workstation design with particular emphasis on layout and dimensions (British Standards Institution, 2004).

- **Part 5: Displays and controls**
  This part presents principles and gives requirements and recommendations for displays, controls, and their interaction, in the design of control-center hardware and software (British Standards Institution, 2005a).

- **Part 6: Environmental requirements for control rooms**
  This part gives environmental requirements as well as recommendations for the ergonomic design, upgrading, or refurbishment of control rooms and other functional areas within the control suite (British Standards Institution, 2005b).

- **Part 7: Principles for the evaluation of control centres**
  This part establishes ergonomic principles for the evaluation of control centers. It gives requirements, recommendations, and guidelines on evaluation of the different elements of the control center, i.e. control suite, control room, workstations, displays and controls, and work environment (British Standards Institution, 2006).

EEMUA 201 - Control rooms

The Engineering Equipment and Materials Users Association (EEMUA) has published a guide on control room specification, design, commissioning, and operation - also known as EEMUA201. It is not a standard, but a guide, with the intention to provide guidance on how a control room can be designed and/or upgraded in the most efficient way. The objective of the document is to help engineers and design teams to develop solutions that are consistent with the requirements of users, which will result in safer and more cost-effective operation of industrial systems. As well as the guide identifies the main issues that influence the effectiveness of a control room and its role in supporting the operation of a wider system (EEMUA, 2019).

2.5 Underwater robotics and autonomous vehicles

The use of underwater robotics can according to Holmstrøm et al. (2019) and Kydd, Macrez and Pourcel (2015) potentially transform the oil and gas industry in the future. Looking at HSE and the operational, can we already see that it is underway. Today is it more and more common to use Underwater Intervention Drones (UIDs) when performing inspection, maintenance, and repair (IMR) operations on offshore/subsea facilities in O&G, and they have shown to be great and important tools for inspection and maintenance on subsea facilities (Holmstrøm et al., 2019). The technological improvements and innovations seen in the lasts decades have made it possible to perform these, often dangerous, tasks using robots and therefore removing humans from dangerous environments. They also lead to a reduction in costs, efficiency increase, and production.

UIDs are unmanned underwater vehicles (Figure 2.7), which means that they are operated from a control room, either locally (e.g. from a vessel) or remotely, and can be given a level of autonomy. They can also be docked on the seabed using docking stations, and communication goes through optic fiber cables and/or acoustics. The UIDs are equipped with sensors and instruments making it possible for them to perform on its mission(s), including camera(s) for view.

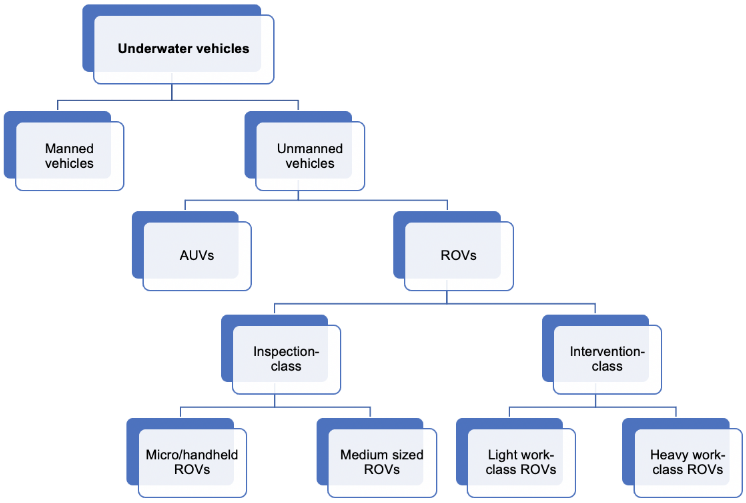

Figure 2.7: Outline of underwater vehicles

The Norwegian Continental Shelf (NCS) alone has over 500 subsea wells (Schjølberg and Utne, 2015) that need to be maintained and inspected occasionally. The demand for IMR on subsea installations will just continue to increase as the number of subsea installations for oil and gas production is increasing, existing subsea infrastructure is aging, more complex structures are deployed subsea. The industry poses strict demands for inspection and maintenance, and information retrieval and preventive maintenance can reduce costly repairs (Liljebäck and Mills, 2017). Using UIDs and new technology to perform these tasks will reduce time spent on IMR and ensure HSE for the workers involved in the operation.

2.5.1 Remotely Operated Vehicle (ROV)

As seen in Figure 2.7 is a remotely operated vehicle (ROV) one type of unmanned underwater vehicle which is commonly used in IMR operations because of its "arms". The drone is remotely operated, primarily using an umbilical/cable connecting it to a controller that is maneuvering its movements from the support vessel.

The tether, however, has its up-and down-sides. The great side of it is that it provides the ROV with its needed power supply to perform its tasks, exchanges data with the operator in real-time, and ensures two-ways-communication. Having high payload capacity, the umbilical also provides the operator with sensor reading and video. Nevertheless, the tether limits the ROV and can serve several unwanted challenges. First of all, the cable can reduce the mobility of the vehicle due to cable strain and entanglement risks (Campagnaro, Signori and Zorzi, 2020), which limits its spatial coverage. The cable is also not well suited for exposure of current loads/drag forces and the forces or big movements can degrade the sampled data. Lastly, operating an ROV is expensive, as the operator must be on-site. The last "problem" can be solved by "docking" the ROV on the seabed, connecting the cable to a power source attached to the seabed, but it will still be limited by its tether.

Figure 2.8: Oceaneering's Magnum Plus ROV (Oceaneering, 2021)

As seen in Figure 2.7 can ROVs be divided into two classes: inspection-class and intervention-class, which again are divided sub-classes. Intervention-class, also known as work-class, ROVs are typically used for heavy operations. The ROVs are usually hydraulically actuated systems and can therefore carry out heavy-duty work i.a. drilling support and construction. They can also operate at depths up to a couple of thousand meters. Inspection-class, also known as observation-class, ROVs typically have a smaller footprint than intervention-class ROVs. They can operate at depth up to a few hundred meters, and are typically used for inspection, surveys, and mapping. However, they can also carry out small tooling operations such as cleaning, latching, or recovery of items. (Capocci et al., 2017).

2.5.2 Autonomous Underwater Vehicle (AUV)

Autonomous Underwater Vehicle (AUV) is the second type of unmanned vehicles one can operate and they are known for their torpedo-shaped figure. It differs from ROVs as it does not have an umbilical cable, and is therefore not directly connected to a vessel/platform or onshore installation. AUVs are typically used for surveys and mapping of the seabed, as they have a greater range than ROVs, but can also be used to perform IMR tasks.

AUVs are autonomous robots, which means that they can perform tasks without being directly connected to the operator, such as move without direct assistance. Operating the drone requires a team of people with high competence and training. Not having a tether makes the up-time of an AUV dependent on batteries to get the necessary power supply, but one avoids the challenges that the umbilical brings. Note that AUVs are not spotless either. There are risks when operating the drone, with the most extreme - loss of the vehicle. Other potential risks are loss of data, (temporarily) loss of navigation and control, collision/meeting with other objects (e.g. ships and ice), and lastly loss of power.

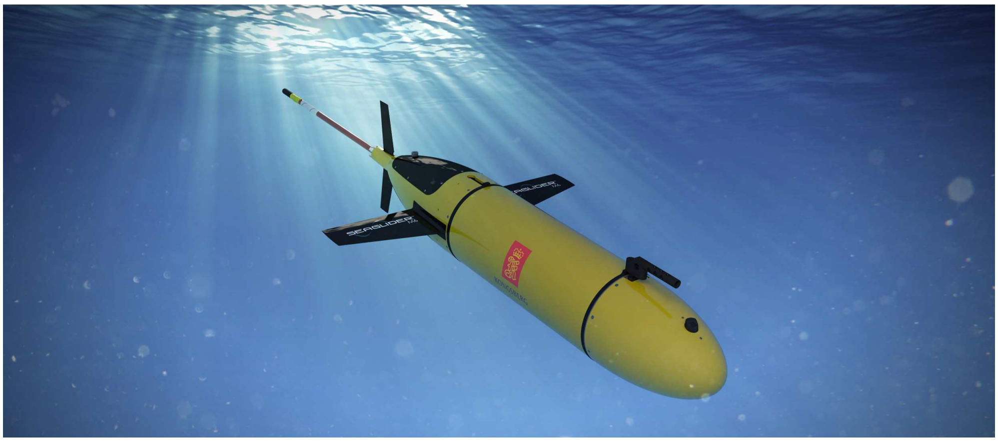

Figure 2.9: Kongsberg's Seaglider AUV (Maritime, 2019)

Like ROVs can AUVs be docked at the seabed. For this, it needs a docking station or plate that is connected to shore (or a power source nearby) by an (optic fiber) cable. The cable is for data transfer and communication, as well as power. Docking is a potential charging station for the AUV as well as a data dumping station. The data collected by the AUV will in some cases not be transferred to the control room in real-time, either because there is no need for real-time data or because one does not have good enough transmission for it to deliver the data in real-time. While docking, it is also possible to upload new mission plans for the AUV. Communication can also happen through acoustics.

There are many applications for AUVs, but they can be grouped into three main categories: offshore/commercial, scientific, and defense. Similar to ROV they have a high payload capacity, but lesser. One of the many pros with AUVs is that new research on autonomy improves its intelligence and ability to operate in an unstructured environment, especially in areas that have limited or no accessibility with other platforms.

2.5.3 Snake Robots (Eelume)

When talking about unmanned underwater robots, one primarily referrers to ROV and AUV (as described above). However, there is another kind of UID worth mentioning that has received considerable attention in the last few years - the snake robots. These robots are different from ROVs and AUVs in the way that they are more flexible and have a narrow cross-section, which provides significant advantages over existing ROVs, especially when it yields for IMR-work (Liljebäck and Mills, 2017).

Eelume is a Norwegian-developed snake robot that is designed to permanently live on the seabed acting as a janitor for the underwater facility where it is docked. It is composed of a chain of joints, thruster modules, and various payload modules, and is remotely controlled from a control room (onshore or vessel). It offers a capability that no other underwater vehicle can, as it can be resident, autonomous, or controlled by an operator. It can also change its shape to reflect the requirements of the task at hand (Liljebäck and Mills, 2017).

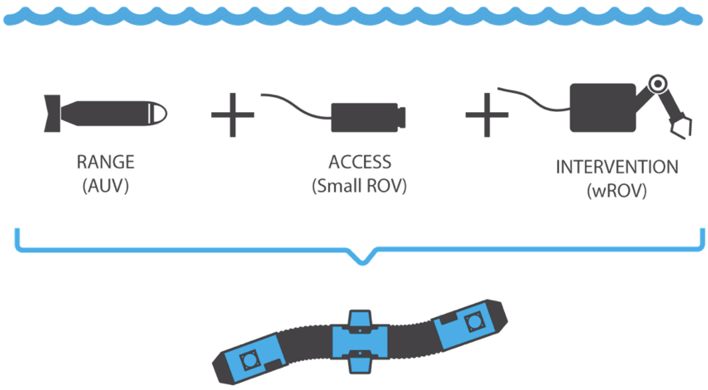

Figure 2.10: Illustration of the snake robot Eelume (Liljebäck and Mills, 2017).

2.5.4 Subsea Drone Docking

One of the benefits of using UIDs is that they can be stationed at the seabed using a docking station or a subsea docking plate which replaces the need for an operator to go out with the drone for it to be able to operate in an area (Holmstrøm et al., 2019). Docking is the process from where a subsea drone purposefully transitions from a state of free flight to be physically connected to another device (Bellingham, 2016). When docked, the drone can charge its batteries, data is downloaded from the drone to docking station (and sent further to shore), new missions uploaded, software updated, etc. This process dramatically reduces operational costs and increases deployment duration (Bellingham, 2016). Another motivation with subsea docking is that it gives continuous and persistent data from the site, as the drones can perform tasks continuously. The docking plate works as a communication link between the drones and the people onshore, as it up-and down-loads data from both parts. Resident drones can also increase the availability for use of the drone within a given area considerably compared to if the drone has to be flown/driven in from another area, and/or if an operator has to go out to the operating site with the drone (Holmstrøm et al., 2019).

However, resident drones place new demands on the drones and the surrounding infrastructure. Such requirements include that the drones must be able to operate for a longer without the need for maintenance performed by humans (Holmstrøm et al., 2019). It also requires safety systems such as authentication of the drones.

2.5.5 Autonomy and Automation

Placing UIDs (semi-)permanently on the seabed in "garages" makes the need for surface vessels lesser and one needs fewer people offshore, but it makes the need for autonomy and automatic solutions higher. There is no human operator placed offshore, everything is remotely controlled and operated from shore, and some processes can/should/are autonomously performed, as the drones are given a level of autonomy (LoA) (described in Table 2.5). This means that one shifts the operator from direct control to supervisory control, where the operator's role is to manage the automation (Lee et al., 2017) to some degree, while the drone/system makes decisions about its actions while performing a task, without the direct involvement of an exogenous system or operator (Grøtli et al., 2015).

Table 2.5: Levels of Autonomy (from US Navy Office of Naval Research and used by SEAS DTC) (Grøtli et al., 2015) There exist several definitions on a given level of autonomy on machines, however, is this the one chosen for this case.

Level	Name	Description
1	Human Operated	All activity within the system is the direct result of human-initiated control inputs. The system has no autonomous control of its environment, although it may have information-only responses to sensed data.
2	Human Assisted	The system can perform an activity in parallel with human input, acting to augment the ability of the human to perform the desired activity, but has no ability to act without accompanying human input. An example is an automobile automatic transmission and anti-skid brakes
3	Human Delegated	The system can perform limited control activity on a delegated basis. This level encompasses automatic flight controls, engine controls, and other low-level automation that must be activated or deactivated by human input and act in mutual exclusion with human operation.
4	Human Supervised	The system can perform a wide variety of activities given top-level permissions or direction by a human. The system provides sufficient insight into its internal operations and behaviors that it can be understood by its human supervisor and appropriately redirected. The system does not have the capability to self-initiate behaviors that are not within the scope of its current directed tasks.
5	Mixed Initiative	Both the human and the system can initiate behaviors based on sensed data. The system can coordinate its behavior with the human's behaviors both explicitly and implicitly. The human can understand the behaviors of the system in the same way that he understands his behaviors. A variety of means are provided to regulate the authority of the system with respect to human operators.
6	Fully Autonomous	The system requires no human intervention to perform any of its designed activities across all planned ranges of environmental conditions.

Using drones to perform tasks that are impossible, hazardous, difficult, or unpleasant for people, removes the risk of human error - which can be up to 80% in some areas. However, one will take away the humans' ability to improvise and manage an unforeseen event (Holmstrøm et al., 2019). Autonomy is built up around trust and finding the right degree/level of autonomy is a challenging task. When it works well, it usually works very well and we sometimes give the system more trust than we should (Lee et al., 2017). However, when failures occur, they can often be catastrophic, less forgiving, or at least more frustrating than any potential corresponding failures of a person in the same circumstances (Lee et al., 2017).

Looking at Table 2.5 we see that there are several degrees of automation, system characteristics, that can be given to a machine. Many often misunderstand this division as a linear development towards more and more autonomy, but this is not the case. A system can be designed with machines that have different degrees of automation, as this suits the system(s) best. It is about optimizing human-machine teaming (HMT) and ensure that communication between machine and operator is in place, and the relationship between them will decide which LoA one should operate on. This will vary from situation to situation, of which some operations will be reasonably autonomous, while in other situations there may be a large degree of HMT. This will also yield for the drones in this case.

When it yields for performance characteristics have humans and machines different things they are better at. This is what Paul Fitts calls HABA-MABA, humans better at - machines better at (Lee et al., 2017). "Machines are more suitable for routine monitoring and high accuracy or repetitious tasks, whereas humans are better suited to tasks that require adaptation, integration, and generalization. Humans are superior strategic and tactical planners" (British Standards Institution, 2001a). Examples of HABA-MABA can be found in Table 2.6. Notice that Fitts's list is criticized for its restricted adaptive power, but it provides some seminal work on principles for a priori allocation (Hoc and Debernard, 2002).

Table 2.6: "Fitts's List" comparing people and automation (Lee et al., 2017)

People are better at...	**Automation is better at...**
Detecting small visual, auditory, or chemical signals	Detecting signals people can't
Combining a many stimuli	Monitoring processes for rare events
Perceiving patterns and making generalizations	Ignoring extraneous factors
Detecting signals with background noise	Responding quickly and applying a great force smoothly and precisely
Improvising and using flexible procedures	Repeating the same procedure in precisely the same manner many times
Storing information for long periods and recalling appropriate parts	Storing large amounts of information briefly and erasing it completely
Reasoning inductively	Reasoning deductively
Exercising judgment	Performing many complex operations at once

2.5.6 Dynamic function allocation

Allocation of functions between humans and machines is a process of dividing responsibility between the two and define how they should work together, in addition to who does what. This is a complicated process, as several important factors must be considered in the design process where these functions are allocated. In systems engineering is function allocation concerned with determining the distribution of work between humans and machines early in the design process, well before prototypes or even design specifications have been produced (Wright, Dearden and Fields, 2000). As seen in Table 2.6 have humans and machines different performance characteristics, and the functions should be delegated to the most capable. One should also according to Wright, Dearden and Fields (2000) view human and machines as epistemic equals in terms of their representational abilities, with the goal of automation design ought to be to make intelligent team players.

Functions should be shared between humans and machines so that the human is left with a coherent set of tasks that it can understand and respond to when the inherent flexibility of the human is needed, but without overloading the human (Lee et al., 2017). The system must be adapted for human-machine cooperation, especially for unexpected circumstances and dynamic (not fully controlled) situations (Hoc and Debernard, 2002). A dynamic situation occurs when a system is not fully controlled by its human operator as it is frequently encountered within highly complex and risky systems. In dynamic function allocation is it assumed that the allocation of tasks and sub-tasks to machines and humans can be defined beforehand in a generic way that results in decomposition of the overall task (Hoc and Debernard, 2002). By doing so, one creates a balanced mechanism making the system more adaptive to a wide range of operational parameters (Hildebrandt and Harrison, 2003). However, are dynamic and conflicting demands placed on a working community as a social system from the environment, which means that the division of tasks is renegotiated between the actors continuously. These dynamic situations lead to that the division of labor is dynamically reallocated between individuals based on special conditions that develop in the specific situation. Functions should therefore be allocated dynamically as the environment is not fully predictable and autonomous machines and humans are acting upon the same objects (Hoc and Debernard, 2002).

The concept of dynamic function allocation is consistent with developed perspectives on human factors engineering, and complex systems are seen as joint cognitive systems in which automation is a partially autonomous cognitive agent (Wright, Dearden and Fields, 2000). Dynamic function allocation is about adapting the human-machine system to unexpected circumstances. It is not acceptable if the human operator cannot identify the function to be allocated, as the human is responsible for that the overall task is recognized, and automation can change the meaning of the functions allocated to it (Hoc and Debernard, 2002; Wright, Dearden and Fields, 2000). Dearden, Harrison and Wright (2000) also states that: "As design options for functions within individual scenarios are selected, the recommendations are reviewed to identity functions where different allocations are recommended in different scenarios. Contradictions of this kind may be resolved by recourse to a dynamic allocation solution".

Several methods for function allocation have been developed or discussed in the literature, as well as criticized. Wright, Dearden and Fields (2000) argues that traditional function allocation has the following two weaknesses: "Firstly, that there is more involved in making functions work in practice than is typically represented in function allocation decision making. Secondly, that the relations between humans and technology in a work setting are not static, but co-evolved in ways that change not only the work practice and the technology but also the meanings (or purpose) of the functions allocated to humans and automation". Such a mutual evolution of work and technology can change the meaning of the functions that are distributed to both humans and machines. The claims imply that there must be considered a richer context of work as a part of the decision-making process for function allocation methods, and that one may require a fundamental reconsideration of the scope and limits of function allocation as a design philosophy (Wright, Dearden and Fields, 2000). They also argue that

> "...that function-based work representations such as hierarchical task analysis, organizational flow charts, standard operating procedures, etc. seldom adequately represent the complexities of work as practiced. Consequently, design decisions based on such abstractions lead to less ideal design... There is a gap between the functional abstractions of work of the sort used to inform function allocation decision making and the processes that are required to make those functions work on an occasion of use...thus we are making allocation decisions on an incomplete view of the work, our ability to design an effective division of

labor is compromised" (Wright, Dearden and Fields, 2000).

The aim is to ensure that the allocation recognizes the many different ways in which humans and machines may cooperate, but "It is inevitable that a method that seeks to envisage a work context that will not be created for another 10 years must be abstract from some of the rich detail that will affect the work and the human performance within the work" (Dearden, Harrison and Wright, 2000).

Regardless of how complex the function allocation is, must one still ultimately make some decisions on allocation and accept that there is still a need for improvisation to adapt these to the special situations individuals and groups operate under. However, trying to allocate the functions before starting the design process is illusory, as it needs flexibility and be changeable during the design phase or later on. This is also the case in this project, and we will see that later on in chapter 4.

Chapter 3

Method

This chapter will explain how the problem statement with its RQs will be answered by presenting the used method. The chapter first gives an introduction to the method, then describes how it is implemented and used. Finally, it evaluates and criticizes the method in context of the implementation.

The problem description of this thesis is the following:

> *How to develop/design a control room for operations performed by a fleet of underwater drones (UIDs) in the petroleum industry?*

With the following research questions:

- RQ1. Which functions/systems are necessary in the control room, especially aimed at machines and humans?
- RQ2. How to handle the data and information flows, especially aimed at the drones' work processes?
- RQ3. How to facilitate good cooperation (*samhandling)* between the various parties involved in the operations?

An important aspect of research is how to arrive at the results and not necessarily the results themselves. There exist several methods and approaches for obtaining data relevant to the study. This chapter theoretically explains the chosen research method as well as how it was implemented and used. It also touches on ethics, limitations, and criticism of the method.

A qualitative research method was chosen in this project to obtain data necessary for answering the problem statement and its following research questions. Research is defined as a process that through systematic work can generate new knowledge is increased knowledge (Krumsvik, 2014), and can be obtained with suitable methods. Qualitative research is a method defined as a specific research technique, which can be interviews, observations, document analysis, etc. (Krumsvik, 2014). The problem in this thesis is answered through interviews, and the results presented in chapter 4 are based on these interviews.

3.1 Understanding the Method

A qualitative research method is characterized by searching for an understanding of a social phenomenon, either by reaching out to people in the field by conducting interviews or by observation in their real setting or by analyzing text and visual forms of expression, to understand their perspective (Krumsvik, 2014; Thagaard, 2018). The studies are attributed both by the fact that we develop theoretical perspectives based on analysis and by the data, and that we take as our starting point theoretical perspectives from previous studies. In most studies, the analysis implies that we alternate between developing perspectives from data and that we take as our starting point ideas from overall theoretical perspectives. The qualitative method is also known for its flexibility, as it is possible to make changes and improve or develop the design of the project during the research process.

The purpose of a qualitative method is to highlight processes and meanings that cannot be measured in quantity or frequency, but by quality looking at the characteristics and character traits of the studied phenomena. Compared to a quantitative method, which has a high number of studied units, does a qualitative method just include a few participants. This gives an inductive approach to the analysis as the findings are based on "rich depictions" (Krumsvik, 2014). Another difference between a qualitative and quantitative method is the researcher's position in the study. Field studies are often used and the researcher is often the primary instrument for data collection and analysis (Krumsvik, 2014).

In *"Systematikk og innlevelse"* has Thagaard divided the qualitative method into four main phases (as seen in Figure 3.1). This division is used as a base for understanding the method in this thesis, as well as its implementation.

Figure 3.1: Overview of the four phases in qualitative method

3.1.1 Phase 1: Formulate Research Questions and chose Design

When developing a research study one must start by defining the goals of the study. These goals will be the center of the study and give guidelines on how to design the study, like the choice of method, selection, and analysis scheme that is relevant for the method.

Firstly one starts with defining the problem statement. The research is often centered around a question that the project will try to answer, the problem statement, which again is centered around the topic(s) that the research project will provide. To ensure that the question does not gap above too much is it often narrowed down by a couple of research questions, that reflect the boundaries of the study so that good quality is achieved (Krumsvik, 2014).

When the problem statement is chosen is a design built around it. The design is a plan for how the study will be conducted and includes descriptions of *what* the study will pay attention to, *who* should participate, and *how* it should be performed (Thagaard, 2018). There are different types of design one can choose for its studies, such as time-design and case studies. One important aspect of the design is to make it flexible such that it will be possible to change the plan and strategy for the project during the project, based on the experiences achieved so far (Thagaard, 2018).

The next step is to choose the methodological approach(es) relevant to the problem statement. How to collect data or which sources are we using, are central here. Are we looking at data that already exist or are we collecting new data from the field? These sources can include text, visual recordings, observations, and/or interviews.

The fourth step is to select the participants or sources. As the selection in a qualitative method is relatively small, is it important to choose wisely (Thagaard, 2018). Then the participant must be recruited.

3.1.2 Phase 2: Develop Data

After the project is designed and methodological approaches are chosen, must data be collected - or "develop data" as Thagaard uses, from participants in the study. This is the process where fieldwork becomes data.

The most common method in a qualitative method is to perform interviews. Interviews can be conducted one-to-one or in groups, depending on the problem statement and design. One can also do observations and participation in the field, diary studies, and case studies. The goal with interviews is to gain rich and comprehensive knowledge on how people experience their situation and get their views and perspectives on the research themes (Thagaard, 2018).

There are three main ways to perform a qualitative interview:

1. No/little structure: The interview is centered around the main theme(s) of the study, but has no or little structure. It is almost like a conversation between researcher and interview object.
2. Structured: The opposite of no structure. The questions, and their order, are chosen in advance. This makes it easy to compare results.
3. Semi-structured: Is often based on a semi-structured interview guide and is the most common interview method. The themes are mainly determined in advance, but the order is determined along with the interview. The structure is flexible, which makes it possible to include new questions and themes and to dive into the fields where the participants have the most knowledge.

Before the interviews are conducted must there be developed an interview guide. The guide is based on concrete themes but with the opportunity to follow up with non-written elements or general questions ("tunneling") (Krumsvik, 2014). The questions should be naturally formulated and open. One should avoid yes/no questions and rather ask questions that capture the interview object's opinions or experiences and ask them to elaborate. After an interview is conducted it must be transferred to text - transcribed. This to get a reconstruction of the interview session. The most effective way is to take audio recordings of the interviews but to do so, one needs (written) consent from the participants. For observations can one make memos or a report describing the researcher's experience. One should transfer the developed data into writing as quickly as possible while it is still fresh in mind.

3.1.3 Phase 3: Analysis and Interpretation of collected data

The data developed, e.g. text, documents, verbal, audio, and video, needs to be analyzed and interpreted. There are several analyzes to chose from depending on the data material. However, there are two main analytical approaches: context analysis and cross-sectional analysis. A context analysis approach analyzes the phenomena in the context of which they are a part of. It is aimed at developing a holistic understanding of the phenomena we study. The cross-sectional approach explores the themes by comparing data on the same topic for all participants in the project (Thagaard, 2018).

Before starting the analysis, the first step is to get familiar with the data - getting an overview of its content. Then the next step is to choose an analytical approach. For both approaches are coding and categorization of the data central. A code in qualitative inquiry is, according to Saldana (2009): "... a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data", where the data comes from interview transcripts, field notes, journals, etc., (Saldana, 2009). There exist many methods for coding data, and Saldana in his manual, sections the methods into two cycles: first and second cycle coding. First cycle methods are those processes that happen during the initial coding of data and are divided into seven subcategories, while second cycle methods are a bit more complicated as they require more analytic skills (Saldana, 2009).

The purpose of coding and categorization of data is to simplify it by sorting and identify patterns. CAQDAS (computer-assisted qualitative data analysis) can be a useful tool for this. Data programs are better at sorting and classifying huge amounts of data and are therefore help full. It will also be a time-saver for the researcher, as it then can concentrate on the reflection and development of perspectives in the patterns (Thagaard, 2018). However, this work is time-consuming and demands analytical skills.

3.1.4 Phase 4: Presentation of Results

One of the goals of qualitative research is to convey the results in a way that gives the reader an understanding of the social phenomena the research is about. The results will have a meaningful character based on the developed data. It will also reflect upon the interpretation and the understanding of the researcher.

Thagaard (2018) points to three aspects that a qualitative text should reflect upon reliability, validity, and transferability. Reliability can be achieved by the argumentation of chosen method for data development, validity by explaining the theoretical starting point for the project and the decisions made along the way how the data are interpreted, and transferability by discussing how the understanding we have arrived at may be relevant in a larger context (Thagaard, 2018).

When presenting the research is it common to include quotes from interviews or descriptions of situations from the field to elaborate points. Doing so gives the reader a more authentic impression of the results. The results can also be presented in models, metaphors, and so on. Qualitative texts are characterized by how it links concepts to patterns and trends that the data represents. The relation between theory and empiric varies greatly between different studies, and the interpretation of the data is therefore what makes the study's credibility (Thagaard, 2018).

3.1.5 Ethics

Several ethical aspects need to be taken into account when conducting a qualitative study - as it must be taken an ethical assessment for any research project. This yields both for which themes that are ethical sounded and how the study is set up to avoid adverse consequences for the parties involved (Thagaard, 2018). Performing a qualitative study involves exploring human processes or problems in their setting (Postholm, 2005). It is therefore the ethical aspects focused around informed consent, confidentiality, and possible research-related consequences for the participants, that are most central in a qualitative research study.

The consent form from the objects involved is what forms the basis for the study, and as a researcher is it important to make sure that their anonymity and rights are safeguarded (Thagaard, 2018). In Norway shall all projects (both student and research projects) which contain processing of personal data be reported. 'Notification Form for personal data' refers to personal data as "... any data that can be linked to a person. Personal data can be, for example, national ID number, name, or e-mail/IP address. A person's voice on a sound recording is also personal data." ('Notification Form for personal data'). Combinations of data that can be linked to a person are also defined as personal data. How to report the project depends on whether it is a notification obligation or licensing obligation. For the last one, is this regulated in the Personal Data Act and the Research Ethics Act, but for the first, it is NSD (Norwegian center for research data) that is the privacy representative for student projects.

Another important aspect is how to act around the participants to ensure that they are not harmed by the study. This centers around the use of language, themes, and questions, body language, accent, etc. In Postholm (2005) is a list with guidelines for how to develop ethical research data presented. This includes requirements regarding avoid injury and pain, consent, information, respect for the individuals' privacy and relationships, confidentiality, and respect for human dignity. These are handled through project registration, legislation, consent forms, and good and reflective implementation of data collection.

3.2 Implementation of method

A summary of the method in general from the previous section is presented in Figure 3.2. This section presents the details for this project and how the student proceeded with the method. Only the three first parts are covered, as the last one, results, is this thesis.

3.2.1 Phase 1: Problem Statement and Design choice

The problem statement in this project: "how to design a control room for inspection operations using a fleet of underwater drones (UIDs)", is based on the conclusion in the student's specialization project (delivered in December 2020) and the capability stack model (presented in Figure 2.3) and is further described in chapter 1.

Designing a control room needs much work both organizational and technical, and not all elements

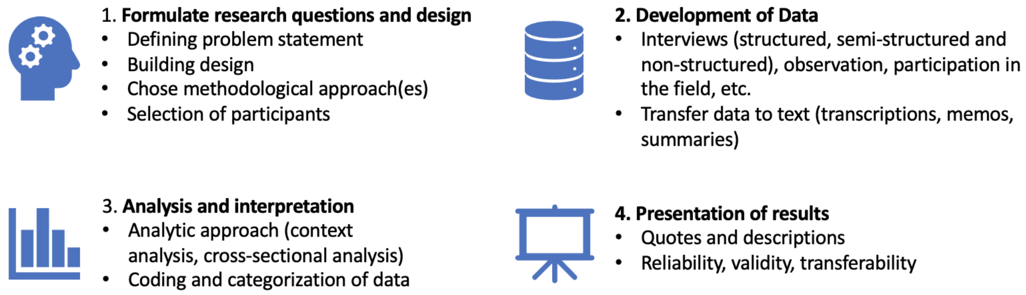

Figure 3.2: Summary of the four phases presented in section 3.1.

of the design would be feasible given the time and resources of this project. The scope is too large as there is so much to consider. To make the task affordable it was therefore narrowed down by the following three research questions:

RQ1. Which functions/systems are necessary in the control room, especially aimed at machines and humans?

RQ2. How to handle the data and information flows, especially aimed at the drones' work processes?

RQ3. How to facilitate good cooperation (*samhandling)* between the various parties involved in the operations?

Based on the problem statement was it clear that a qualitative method was the best approach for this study, as it asks for functions/systems needs and qualities in a control room for UIDs. To be able to detect the functions needed in such a control room was it natural to reach out to relevant people who work with similar problems or disciplines to find out what they thought was necessary to implement based on their expertise. 1-to-1 interviews were seen as a natural choice to gather this information.

Applications and Approvals

Before sending out invitations to relevant subjects, the project had to be approved by NSD. This to ensure that rules and regulations regarding privacy and data protection were adhered to, especially since recordings of the interviews were desirable.

An application was sent to the Norwegian Centre for Research Data (NSD). This was done by filling out a form on their web page, explaining the intentions of the project, wanted participants, how the participants should be contacted, how their privacy was supposed to be guarded, etc. NSD then went through the application to see whether the project met the requirements for the protection of data and privacy, and that legislation was followed throughout the project. The application for this project was approved by NSD, as seen in subsection A.

Invitations and selection of Interview informants

Relevant subjects to be interviewed were suggested by supervisor. They were all invited to participate in the study through personnel email addresses provided by the supervisor (subsection B).

16 persons got the invitation and 10 responded and participated in the study.

From the list of relevant informants given by the supervisor can one find people from different companies and areas of expertise. On the list were researchers, developers within soft- and hardware, project managers, and academics. A few of them had experience from control room operations, others just experience with robotics and drones, and some of them no experience from either side, but with other relevant perspectives.

In the distributed invitations was the project described in brief with its problem statement, research questions, and intentions. In the email sent out was it further explained how the interviews would be conducted. The interviews were set to have a duration of one - 1 - hour and were performed digitally using Microsoft Teams. As a result of the covid-19-pandemic has the use of digital meetings increased and the threshold for participation digitally has decreased as the meeting tools have been easier to use and better. Also, uncertainties regarding (local and national) infection rules and recommendations, as well as usage of home-office, were influencing factors for the choice of conducting the interviews digitally. It also made it easy to interview people outside Trondheim. The subjects got to suggest time slots for the interview so that it could fit into their schedule. The only constraint given was that it should be before Easter/the end of March.

3.2.2 Phase 2: Development of Data

Interview Guide

Before conducting the interviews, an interview guide had to be developed, as seen in subsection D. The guide included several questions related to the problem statement and the research questions and was categorized into seven categories: functions, technology, data-streams, collaboration, training and competence, development features, and challenges. It also included a yes/no question about knowledge of ISO 11064, as part 1 of the standard was used as a base for the guide.

The categories in the guide were divided into four parts:

- Beginning: The interviews started with a brief introduction to the project, the student's background, and the plan for the interview. Then the participant got the opportunity to tell a little about themselves and their background and experiences. This to warm up and get to know each other a little before entering the main part.
- Part 1: Questions and themes related directly to the control room (functions, technology, competence), as well as allocation of functions to humans, machines, and integration of both.
- Part 2: Questions and themes related to aspects outside the physical control room, such as the drones, data-streams, collaboration, etc.
- Ending: This last part was to "cool down". Before ending the interviews, the participants got the opportunity to ask some questions or comment on the content of the project, and/or how they experienced the interview. It was also asked if they would be available for follow-up questions in the time after the interview. Then they were all thanked gratefully for their participation and help.

The interview guide was developed based on a semi-structured approach giving the necessary flexibility for the student during the interviews. Thagaard (2018) points out how important it is to ask questions that encourage the participants to give concrete, but complementary answers to achieve great quality, from which one can get descriptions of experiences and happenings relevant to the problem from the interview objects. This is something that was in mind when the interview guide was developed and questions not directly from the interview guide, but about its topics, were frequently asked to gather more information on interesting viewpoints.

Conducting the Interviews

Before conducting the interviews, the participants had to sign a consent form, subsection C, giving their written approval on recording the interview and use it for research. Microsoft Teams also has a pop-up window that says that if you are in the "room" you are consenting to the recording when the recording function is turned on, else you have to leave the meeting. This was no problem for the objects and it was pointed out that only the audio recording was to be used further for those who were a little skeptical about having the camera turned on. In some cases were a new Teams-invitation sent out, this time from the student's NTNU-account. This had something to do with how recordings are saved in Teams [1]

All of the interviews were conducted in Norwegian as all subjects were Norwegian. Not having a language barrier led to comfort for both parts and facilitated better flow as both parts could use their native language. The interviews were mainly performed using a semi-structured method, but some of the interviews can be placed under no/little structure. This had something to do with the interview subject's experiences and background.

The plan from the start was to have a semi-structured approach to the interviews, and the interview guide was designed according to this. The reason for this choice was that it would make it easy to ask follow-up questions on the topics, experiences, concepts, ideas, and projects the objects highlighted during the interview. Not all the questions in the guide were asked, as some of the objects touched into or answered the questions during another question, and then it was not seen necessary to ask them further. In a few cases were there not enough time to go through all questions/topics, and the most important questions were prioritized. However, in most cases, were all seven categories touched into, but with a varying number of questions, depending on their answers and expertise. It was rare that the categories/themes were slavishly followed - which is also common in semi-structured interviews.

As mentioned, were some of the interviews conducted with non or little structure. These were typical interviews with people only having experience with one side of the problem statement or were the only one with a specific background that it was interesting to deep dive into and have a more open discussion with. These interviews can be seen more like conversations, where both parties asked and answered questions, but with the student in charge. It was often these interviews that were most interesting, as they gave a new or very different perspective on the given case compared to previous interviews. These interviews also introduced new challenges that gave the student something new to think and reflect about. The mix of semi-structured and non/little structured interviews felt natural and has later on proven to be very useful.

The student had never used a qualitative method before and was a bit nervous and stressed out before the first interviews, as she had no previous relationship with the persons in question, nor did she know what they were thinking about the issue in focus. However, it turned out to go well, as those who participated were very nice and receptive, and wanted only the best for the student

[1] Further description of how recordings work in Team can be found here, in addition to how it works with an internal and external organization.

and assist in the work. Some also thought it was a bit stately to be asked to participate. Having the interview guide as a basis, also made it easy for the student to calm her nerves, and she felt more and more steady for each interview.

The interviews went very well, and the time was almost always used up. Having a full hour for each interview gave a pleasant pace and atmosphere, as there was no need for rushing through the questions and much time to think and reflect. Since it was only given a brief introduction to the project beforehand in the information letter, and later at the beginning of the interview, were the objects given some time to think during the interview, and it was good to have time for this. It also gave the student some time to reflect on the answers and to find out how to navigate the interview guide.

Table 3.1: Interview objects

ID	Field of experience
1	Oil company, petroleum technology
2	Researcher, robotics
3	Researcher, human factors
4	Researcher, marine robotics and software
5	Project manager
6	Oil company, IT
7	Oil company, human factors
8	Researcher, marine operations
9	Researcher, robotics and hardware
10	Oil company, IT

3.2.3 Phase 3: Analysis and Interpretation

Transcription

All 10 interviews were transcribed into text, word by word, within the first week - 7 days - after it was completed. This was a requirement presented in the consent form, (subsection C), and a motivation for the student to finish the transcription while the interview still was fresh in mind, especially if it turned out to be some obscurities in the recording.

The transcription was done in two steps: First, the recording from the interview was dictated into Microsoft Word by Word's built-in function for dictating. Secondly, the student went over the document to make sure that the written content matched the recording as well as giving it some structure (such as line-shift, comma, and period). The second round was also necessary as Word is sensitive to the Norwegian language and its dialects, and therefore misinterpreted words and sentences.

Some interview objects were very talkative and talked a lot about their own research and experiences related to it, or gave examples about similar events. The necessity of including these in the transcript file was evaluated and was in most cases removed or cut back on. The main reason for this was privacy as the research they were talking about was directly traceable. In other cases was text removed because it was seen as completely unnecessary and not related to the study at all. Removing this text contributed to the compression of the files, which averaged around 10 pages each, with important claims and design requirements. It also made the analysis work tidier.

To make sure that the privacy of the participants was ensured, were the interviews saved only with an ID number (as seen in Table 3.1), not containing any personal information about the object. Names, background, and email addresses were saved in a separate Excel form. The video recordings were deleted after transcription. As the interviews were conducted in Norwegian, were the transcriptions "translated" to *bokmål*, so that the objects would not be recognizable by their dialect. After the deadline for the thesis were the also the transcriptions deleted.

Coding and Categorizing

For the analysis of the interviews was NVivo used. It is a qualitative research tool/software that NTNU has a license on, making coding and categorization easy and clear.

A combination of an inductive and deductive approach was used for making codes. This because the research questions and questions in the interview guide gave some logical categories, grouping, and individual codes (deductive coding), but as the material was analyzed, new codes were derived (inductive coding). After a round of coding the interviews, the codes were organized further into categories and sub-codes. From there on, new rounds of coding were derived to re-examine the codes and categories, as well as merging similar codes, re-naming, and re-categorizing the codes.

Only codes with relation to two or more files were kept in an attempt to reduce the number of codes. Codes connected to only one file were written down as a peculiarity for the given interview. This was especially true for the interviews that had a non-structural approach, focusing on a special part of the problem statement.

A total of three main categories were determined, one of which again was divided into two sub-categories. The results from the coding with its categories are presented in Table 3.2. As seen, are technical functions dominating the list, which is natural, as one of the goals in this thesis is to perform a function analysis focusing on technical functions or systems related to humans and/or machines. Organization and collaboration match RQ3, and challenges and needs focus on the development of technology and what must be in place for this control room in the long run (cf. the development plan). In the sub-category "control, management and observation" is there also two codes with sub-codes. These focus on special aspects within the code.

As mentioned were some statements removed from the transcription files as they were not relatable to the case, comprising the files. However, there was still a lot of text that remained and had to be analyzed according to the case of the thesis. In one of the first rounds of reading the transcriptions were all possible functions/design requirements written down in a separate document along with necessary data readings. Later on were the functions coded in regards to its functionality, which resulted in the categorization as seen for technical functions in Table 3.2.

The "technical functions" are the answer to the functional analysis and is divided into two sub-categories, respectively to hardware and software specifications. "Data management, processing and collection" contains the functions/systems related to data flow and management, as to how data should be processed, collected, and transferred, as well as for how errors should be administrated. These are functions that are primarily related to the software and HMI, but which also are important for the operator in terms of visualizing the data output.

"Control, management and observation" are primarily about the drones, as for which functions/systems that the control room operators need to control and manage the fleet. It also contains codes for the roles of humans and machines, as well as their interaction. This is the category that contains the functions that affect the control room the most, in regards to autonomy and HMT, as the technology is not far enough developed for the control room's use. This forms the basis of the discussion around dynamic function allocation, presenting the design requirements for the system.

Table 3.2: Categories and codes from analysis of the transcription files.

TECHNICAL FUNCTIONS	
Data management, processing and collection	**Control, management and observation**

• Data and information of interest
• Data transfer through docking
• Error handling
• Infrastructure
• Interface and visualization of data
• Real-time data
• Technical tools for data processing
	• Alarms, status, reports
	• Autonomy
	  – Accountability
	  – Level of autonomy
	  – Risks and security
	  – Trust
	• Communication
	• Machine
	• Human
	  – Competence and skills
	  – Manual control of drones
	  – Situational awareness
	  – Training
	• Human-machine interaction

Organisation and collaboration	**Design specifications**
• Responsibility • Data and information streams • Communication • Coordination • Control room models	• Flexibility and scalability • Maturity and trust • Robustness • Standardization • Technology optimism

As one will see in chapter 4 does not the interview objects talk directly about dynamic allocation when listing the functions needed in the control room and the distribution of them. It is therefore no code for "dynamic allocation" in the analysis. Finding material/quotes that highlighted the need for dynamic allocation has been challenging since one must interpret the interviews differently to find indirect opinions about this distribution. This also shows that the study evolved as data were developed.

"Design specifications" present the requirements and needs for the design related to the control room and its functions. These are system properties that must be in order to optimize human-machine interaction and that the allocation of functions must facilitate. The design specifications must be utilized in the technical functions to make the system adaptable and enabling continuous development over time and must be taken care of by the organization. Without these design specifications will great value creation be difficult to achieve.

The last category, "organization and collaboration", takes into account the organizational conditions around the division of responsibilities, coordination, and communication within the organizations involved in the operations. It gathers data from the control room and distributes it out to internal or external support functions. It is also here the models for the control room's structure in regards to data and information streams, are placed.

How the main categories are related, is attempted represented in Figure 3.3. In addition is communication a key factor that must exist among hardware, software, and people/organization, which is also an element that goes again in each category directly or indirectly.

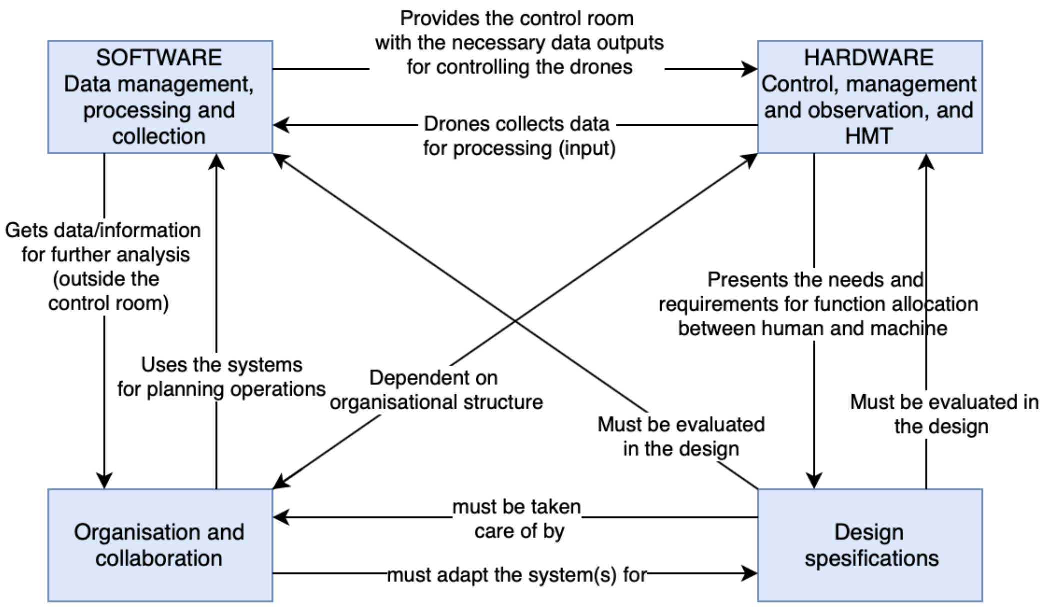

Figure 3.3: The relation between the four main categories from the analysis work of the transcription files.

3.3 Evaluation, Limitation and Criticism of the Method

This section firstly evaluates the chosen method and the interview objects' background, and therefore impact on the presented results. Lastly, it lists up critical limitations to the method, and how this is reflected upon in this thesis.

3.3.1 Evaluation of the interview objects' background

The results presented in this thesis are colored by the answers given by the interview objects and their backgrounds. To get a wider diversity among the participants could it have been relevant to have talked to someone who works in other parts of the industry, but time has been a limitation in this study. Actual personnel to consider talking to are people working offshore (with and without robot experience/expertise) and control room operators from different fields. They have different experiences that could have been of great use in this thesis. There also exist some companies that have proprietary control rooms for underwater drone operations today (like IKM), and talking to them would also have been promising, as well as taking to more people with experience with underwater operations. It could also be relevant to talk to several people in the same position as the ones interviewed but in a different company. These backgrounds and replenishment of competence would have been very useful to have in this analysis, as they bring in completely different perspectives and experiences. Regardless of that, is the width among the interview objects decent, and the selection is therefore seen as good, given the case. However, for further work with the design of this control room can it be useful to talk to some of the actors presented.

3.3.2 Evaluation of method

This study is qualitative-interpretive and there exist some principles that interpretive research studies should reflect upon. Interpretive research focuses on the complexity of human sense-making as the situation emerges and not on predefined dependent and independent variables (Klein and Myers, 1999). The principles, as seen below, are useful in the way that they summarize the most important insights of the study, but not all principles may apply in every situation. Klein and Myers (1999) present seven principles found in Table 3.3, with the first one, hermeneutic circle, as the overarching principle, and the following six expands this principle.

An evaluation of each principle for this thesis is executed and found in Table 3.3, along with a description of each principle.

Table 3.3: Description of the seven principles presented by Klein and Myers (1999) with an evaluation of this project.

Principle	Description	Assessment
1. The Fundamental Principle of the Hermeneutic Circle	This principle suggests that all human understanding is achieved by iterating between considering the interdependent meaning of parts and the whole that they form. This principle of human understanding is fundamental to all the other principles.	In the study has one put small problems at micro-level into a larger context at the macro level, and vice versa, which has increased the insight into the problem case and its challenges. The functions presented are just a small part of the control room, the same yields for the work processes. They are connected and interdependent in the control room (stack model).

Continued on next page

2. The Principle of Contextualization	Requires critical reflection of the social and historical background of the research setting so that the intended audience can see how the current situation under investigation emerged.	The problem case in this thesis is selected based on the specialization project conducted during the fall semester. The project was based on literature analysis/study on sensor platforms and how they can be used in the O&G-industry. During the fall semester did the student build up an understanding of the topic, which is continuing into the work in this study.
3. The Principle of Interaction Between the Researchers and the Subjects	Requires critical reflection on how the research materials (or "data") were socially constructed through the interaction between the researchers and participants.	The functional analysis is based on the results from a qualitative method using interviews to gather relevant functions from people working in the industry and researchers that research the field of interest. There is social interaction between the participants and the student, as the interview is performed one-to-one on Teams. This is further evaluated in subsection 3.3.3.
4. The Principle of Abstraction and Generalization	Requires relating the idiographic details revealed by the data interpretation through the application of principles one and two to theoretical, general concepts that describe the nature of human understanding and social action.	The results in this study are primarily for the specific case. However, this type of control room is generic in the way that it can be utilized in other fields. The results are not final, they are only suggestions based on the expressed needs.
5. The Principle of Dialogical Reasoning	Requires sensitivity to possible contradictions between the theoretical preconceptions guiding the research design and actual findings ("the story which the data tell") with subsequent cycles of revision.	The data collected from the interview objects in the qualitative study have been transcribed and coded for further analysis. How this process is carried out is described in more detail in section 3.2.
6. The Principle of Multiple Interpretations	Requires sensitivity to possible differences in interpretations among the participants as are typically expressed in multiple narratives or stories of the same sequence of events under study. Similar to multiple witness accounts even if all tell it as they saw it.	Presents alternative models, functions, and key stakeholders for the UID-control room. There is no right or wrong in this case, only suggestions that must be evaluated.

Continued on next page

7. The Principle of Suspicion	Requires sensitivity to possible "biases" and systematic "distortions" in the narratives collected from the participants.	The student has not got an impression that the participants in the study have been dishonest or tried to keep things hidden. Much of the information gathered has been mentioned by several objects, and they are all seen as reliable. However, is this study based on things that do not (fully) exist today, meaning that the objects had to use their imagination and experiences when answering the questions. Some participants were very talkative about their own work and research by telling stories, and some were more optimistic than others on the success of the problem case. This is something that has been kept in mind performing the analysis of the transcriptions, and typical "cozy talk" has been cut out of the transcription files.

3.3.3 Criticism of Method

There are several limitations in a qualitative method that needs to be reflected upon. Rahman (2016) and Queirós, Faria and Almeida (2017) are pointing out some of the disadvantages of the method in general:

- **Generalizability**: The collected data are specific for a given case, and the results are therefore not generalizable (can not make decisions based on individual events). Some generic reflections can be used in another case. Sample size also affects this.
- **Small sample size**: The method includes only a small number of participants that might not represent the broader population. This can raise issues of generalizability to the whole population of the research (Rahman, 2016). The participants should be carefully chosen to avoid bias.
- **Time-consuming**: The work is time-consuming. This yields both for the collection of data and the analysis of the data.
- **Credibility**: How the results are presented might be affected by the researchers' own opinions or agenda. It is therefore difficult to tell how far the findings are biased. The results are also colored by the researchers' own interpretation and decisions of the results - it is an internal point of view.

  Stakeholders frequently use quantitative research when research is called upon, and the method can therefore be seen as hints of disguised political persuasion and socially sympathetic approach towards research fields (Krumsvik, 2014; Rahman, 2016)

In this case, interviews are used as a method. When performing interviews one must take into account several aspects that can lead to bias. There are two main types of bias related to interviews: bias arising in content or wording of questions, and bias arising from interviewers and the way in which they ask questions and respond to answers (Waterfield, 2018).

Using Waterfield (2018) as a basis, the following points can have introduced bias to the study:

- **Interview Guide**: The interview guide was developed after some literature review and conversation with supervisor, and was based on the student's primarily understanding of the concept. Questions developed could therefore have their meaning misinterpreted or lost.

  When using interviews as a method in qualitative research, is leading questions something one should avoid. However, in this case, have some of the questions, or follow-up questions, been leading. This with the intention to induce reflection, evaluation, and dig up experiences within the question's specific area or theme. Even though bias is something to be avoided, is it in this case intentional and strategic. The guide was also developed in Norwegian firstly and then translated to English. As there were no interviews conducted in English, will the wording not be affected. However, they can have been affected when it yields for translation for the thesis itself.

- **Information**: The interview objects were given some information on the case beforehand (in the invitation) and this was repeated before starting the interview. It was held shortly to not take up to much of the interview time. There is a bias in that the information given beforehand can have been leading as the subjects might have focused too much on it when answering the questions. Some interview objects came prepared to the interview with notes based on the given information, others did not.

- **Thrust and relation**: The interviews were intentionally started with a "get to know each other"-phase. This was to build a relation and lower the threshold. However, this can have created bias, as the participant can have responded to questions based on how they relate to the interviewer's sex, ethnicity, age, attractiveness, social class, level of education, perceived life experience, or professional background (Waterfield, 2018).

  The Interviews were conducted online using Teams. No physical meetings were performed. This digital distance can have made it "safer" for both parties, as the environment was privately chosen. The subjects also got distributed information about how their personal information would be taken care of, which can have been a factor in the establishment of thrust.

  All interviews were performed in Norwegian, using their dialect. This can have lowered the feeling of formality, making them feel more like themselves.

  As the interviewer is a student, subjects might have been affected by that.

- **Body language**: Interviewer bias may be due to body language, facial expression, or paralinguistic aspects of communication such as tone of voice or emphasis (Waterfield, 2018). Since the interviews were conducted over Teams did not body language play the same role as it does in a physical meeting. However, did almost all participants have their camera turned on, appeared ready, and paid attention.

  As the interviews were recorded with both audio and video could the student evaluate the body language when transcribing. However, this had little to do with the results and more on giving the interview object the time it needed to answer the questions (one could see if he/she was thinking).

- **Expectations and preconceptions**: Interviewer bias may also arise from expectations or preconceptions on the interviewer's part (Waterfield, 2018). This could have affected the performance of the interviews and the analysis. When it yields for the interviews, this will be related to follow-up questions and given examples, how they were formulated. For the analysis, this can have been a factor when it comes to categorization, as information might have fallen outside the selected categories.

- **Results**: The selection of participants can have presented a bias in the results. Their background, experience, interest, and understanding of the case can have affected how they understood and answered the questions.

All in all, we see that the study may present some bias, but it is reflected upon and taken into account. The factor that probably has affected the thesis the most, must be linguistic, where translating the quotes and answers from the interview objects into English may have led to changes in meanings, as the use of terms and wording are slightly different in the two languages.

Chapter 4

Results and Analysis

This chapter presents the results from the study which is based on the answers and accumulated information, meanings, and experiences from the 10 interview objects. As the thesis has a human factor perspective and the interview guide was mainly based on ISO 11064-1, are the results presented based on the design process model for control centers found in the standard, and as seen in Figure 4.1. Not all phases and parts of the processes are included and presented here as they are not relevant for the problem description with its following research questions. The result chapter therefore only includes phase A and some parts of phase B.

Phase A presents the goals and background of the study, going further into the problem description. This part also presents the inspection work processes that the fleet of drones are performing. In phase B is the functional analysis, which forms the foundation of the thesis, presented, in addition to two proposed models for the control room hierarchy with its respective data streams. Lastly, is the proposed development plan presented.

Knowledge of ISO 11064

Since the thesis is focusing on human factors and uses ISO 11064 as a base it was natural to ask the participants if they had any knowledge about the standard before starting the interview.

As seen in Table 4.1 did a total of three - 3 - participants in the study have knowledge about the ISO-standard, whereas two of them are working directly with human factors. One - 1 - knew it existed, but did not know its content. The remaining six - 6 - interview objects did not have any knowledge of the standard, even though some of them are working with control rooms and underwater drones. On the other hand, did not all participants work directly with control room operations and development, which makes the missing knowledge of the standard acceptable.

The six without knowledge about the ISO got a short summary of its content, mainly focusing on the human centered design aspect, as this plays a central role in the thesis. It was not noted that any of the six did have any special knowledge in the field of human factors, which is not surprising giving their background as engineers, looking for solutions to the problem rather the details in the problem itself. This might illustrate the point that human factors are not always considered when designing a project and that human centered design tends to give way in favor of technology.

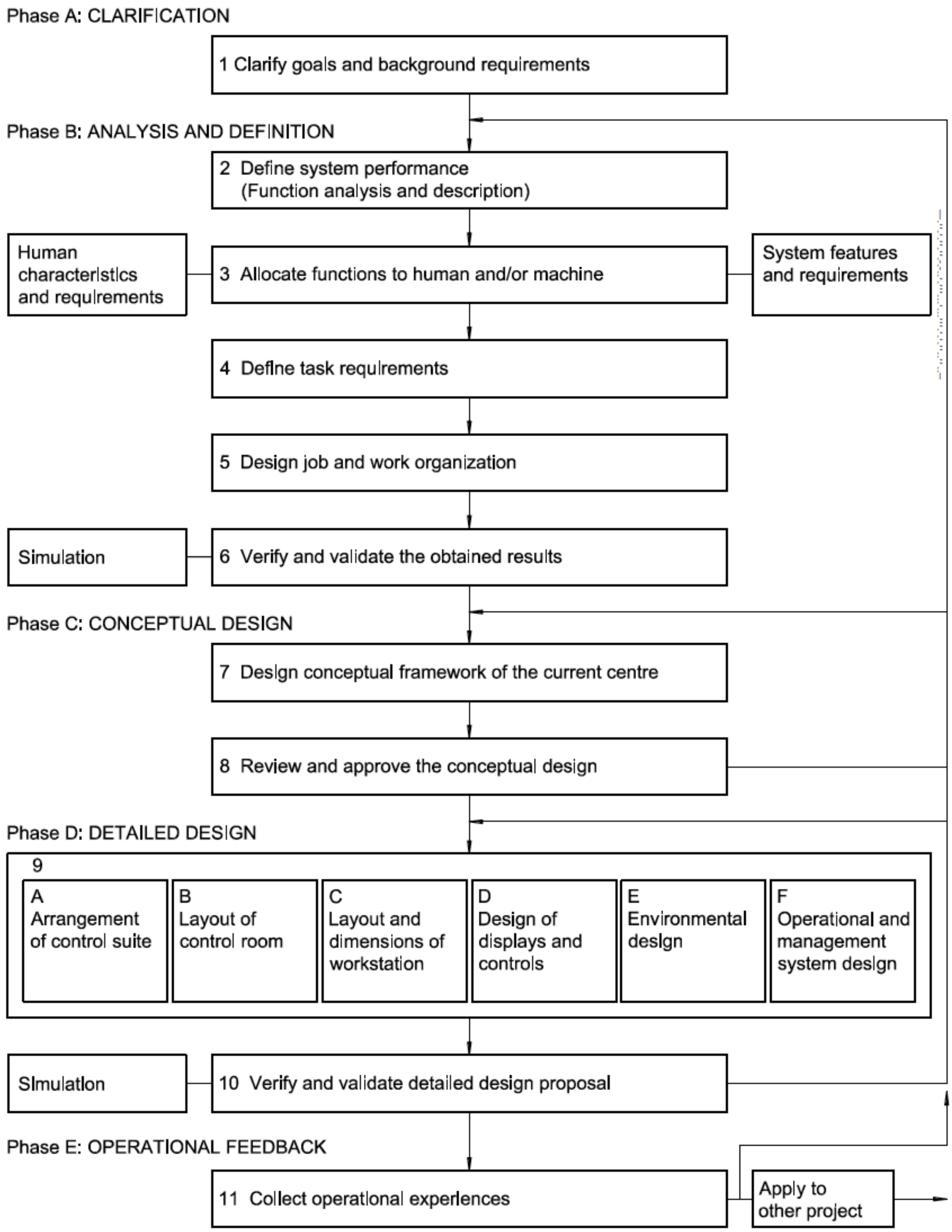

Figure 4.1: Figure of the ergonomic design process fro control centres presented in ISO 11064-1 (British Standards Institution, 2001a)

Table 4.1: List of which interview objects that had knowledge of ISO11064

ID	Field of experience	Knowledge of ISO 11064
1	Oil company, petroleum technology	No
2	Researcher, robotics	No
3	Researcher, human factors	Yes
4	Researcher, marine robotics and software	No
5	Project manager	Yes
6	Oil company, IT	No
7	Oil company, human factors	Yes
8	Researcher, marine operations	Knows it exists
9	Researcher, robotics and hardware	No
10	Oil company, IT	No

4.1 Phase A: Clarification

The purpose of phase A is to clarify operational goals, relevant requirements, and constraints associated with the design of control centers (British Standards Institution, 2001a). This is very important in an HF analysis and forms the basis of this analysis. The problem statement and case in this thesis is described briefly in chapter 1, but is in this section described in more detail using ISO 11064-1 as a base.

The goal of this thesis is to start/begin the design process of a control room for fleet management of (stationed) UIDs in the oil and gas industry, with a focus on human factors. Methods used to obtain necessary information regarding the clarification process are coming from the interview objects through interviews and from literature studies.

The motivation for developing this control room is to remove the top-side vessel needed today to perform underwater IMR-work on subsea facilities, as the vessel sets restrictions/limitations on time, availability, and use, as well as it has high rental costs. By replacing the top-side vessel with underwater intervention drones (UIDs) that are placed on the seabed, will the drones give the necessary flexibility as one does not have dependencies related to the boat, weather on the surface, and waiting time, and makes it possible to perform necessary operations in real-time with real-time data. Using underwater drones and docking stations removes the need for human divers performing work in unsafe zones/environments, and they are better suited for HSE. As new technology and restrictions/legislation's demands for new needs, will a permanently placed fleet of UIDs create new services, as they will act as janitors on the seabed. It also opens up for development in harsh environments.

The drones are controlled and monitored from a control room placed onshore by control room operators (CROs), providing the necessary functions and systems for fleet management. By having a fleet of drones, consisting of several types and suppliers, one gets a diversity that makes it possible to carry out different types of missions. The UIDs can collaborate and assist each other, or be used to give the control room operator(s) different camera angles and other support functions during missions. Using several drones can also give necessary redundancy.

In this control room case is the fleet set to perform three types of operations or work processes which are listed below. It is the CROs that initiate the missions and intervenes if alarms or errors occur, and they have the overall responsibility. They ensure that everything is going according to plan and manage the critical real-time data the drones produces. Non-critical data can be processed by other stakeholders and is communicated out of the room. The work processes listed, are presented in their reversed prioritized order.

4.1.1 Fixed continuous monitoring - background operation

[1] One of the perks of stationing drones at the seabed is that it is possible to perform regular monitoring in a fixed pattern on the subsea facility or its surroundings. This type of operation can be done using high levels of autonomy (LoA), as the drones will follow a predefined grid, and do surveying or environmental monitoring, i.a. sniff for CO_2-leakages or look for anomalies in pipelines. It will also be useful for change detection, as it follows the same grid e.g. every day/week/month. Here, the choice of sensors placed on the drone is important in terms of the type of measurements you want, as discussed in the student's specialization project.

This type of operation can happen quietly in the background without any special attention from the CROs. The drones obtain the ordered data and dump it in the docking station according to its plan. As the operation is marked as non-critical and does not involve high-risk tasks is it not necessary to include other support functions than the control room for handling unforeseen events and alarms and the people included in the data analysis afterward. There is no need for observation of the operation or to make firsthand analyzes of the results. It is just a matter of collecting non-critical data and analyzing it by looking at long-term trends or similar.

Which temporal rhythms, functions, and data sources that are needed for this operation, among other things, are presented in Table 4.2.

Explanation of the table The dashed line between the observation room/center and control room refers to the two possible divisions of the room, further described in subsection 4.2.4. The observation support center can be merged with the control room, but is dependent on the organization and structure of the concept: If the operator wants to control the drones themselves and observe the missions, then they will be merged. Else if the operator wants the drone suppliers to operate the drones and only observe will there be a separation between the two rooms, especially on location. The support center refers to other support functions that have a relation to the control room and the field, but that do not need to be placed in the control room. These can be domain experts, subsea engineers, and mission planners. The data analysis center is all connections outside the control room that analyze and examines the data that is accumulated during the missions. They typically look at long trends and changes in the environment or subsea template. This can be people outside the organization that operates the field.

Professions correspond to the technical disciplines that are involved in the inspection operations. This varies on the type of mission and they all have different temporal rhythms. Temporal rhythms characterize the professionals' ways of working as they have a different understanding of time and their activities are based on this. It is "an analytical approach that highlights a temporal characteristic of work at a collective level is the concept of temporal rhythms. The concept of rhythms directs our attention to the reoccurring patterns of work and how people use their knowledge

[1]This operation was added during the interview phase, based on the information gathered so far.

of these reoccurring patterns during their patient care and organizational activities in the unit." (Reddy, Dourish and Pratt, 2006).

Temporal horizons describe how the tasks should be organized based on the knowledge of when they have to be finished to prepare for upcoming activities (Reddy, Dourish and Pratt, 2006). It refers to the orientation that the professionals have according to what is at stake within their temporal trajectory and what makes up its rhythms.

Temporal coordination is an activity that seeks to integrate distributed collaborative actions. It is about determining exactly when some event will occur or some results will be available in relation to other activities and actions (Bardram, 2000).

There are mainly two ways to transfer data in this case: through docking or by acoustics/optics. Not all data can be transferred in real-time and not all data are necessary in real-time and can therefore be transferred through docking. "Data" in the tables refers to which data the stakeholder needs, as some are more crucial than others. Some parameters/variables (point data) must be monitored continuously, as others can be dumped in the docking station batch-wise (time series). How the data are collected is further presented in subsection 4.2.1. Necessary functions refer to the most important functions presented in section 4.2 for each profession.

Table 4.2: Key temporal constructs for fixed continuous monitoring (e.g. IEM).

	Data analysis center (outside control room)	Support center	Observation support center (operator)	Control room (drone supplier/ contractor and/or operator)
Professions	Domain experts, e.g. oceanographer, marine biologist			Control room operator/pilot
Temporal rhythms	Months and years			Seconds and minutes
Temporal horizons / what	Examines the data accumulated by the drones after docking.			Intervenes if an unforeseen event occurs or an alarm is raised. Makes shortcuts or repriorisations if necessary, e.g. an alarm goes off and the drone(s) is needed somewhere else for check and report mission
Data	Docking			Real-time critical data
Temporal coordination with artifacts (models)	Coordinate data sets, make models, run simulations, etc. Looks at long term trends, predicts and place different types of data into a bigger context, primarily based on multivariate statistics and analysis. Can also use AI and ML to find changes in coral reef in the area that has happened over time.			Does not closely observe and monitor the mission as the drones are operating in a predefined grid (with high LoA). Only interacts if an alarm occurs.
Necessary functions	Data processing and management, Metadata and tags, video			Health monitoring system, dashboard, control and navigation, CCTV, communication, alarm/error system

4.1.2 Planned Inspection

The main objective with inspection is to evaluate and validate the condition of the equipment so that it is functional and to see that its strength can be sustained throughout the life-cycle of the equipment and structures (Hepsø, 2002). It is a part of the preventive maintenance system of the installation and must be regularly executed.

Inspection of equipment is demanded by authorities and has to be planned in detail in advance. Using drones to perform the inspection tasks ensures HSE and having a stationed fleet makes it possible to increase the time interval between inspection rounds in an effort to catch abnormalities earlier. These operations are planned in detail ahead of the operation by personnel outside the control room and then executed by the CROs.

Table 4.3 presents the key temporal constructs for inspection operations. It is inspired by how ROV-missions from vessels are performed, having an online and offline control room, but in this case are they both placed onshore. As seen has the observation part of the control room a more active role in this operation and the support center is included, compared to the previous operation (fixed monitoring). The operation coordinator has the overall responsibility for the planned operation, coordinating the necessary tasks and personnel.

Table 4.3: Key temporal constructs for planned inspection operations.

	Data analysis center (outside control room)	**Support center**	**Observation support center (operator)**	**Control room (drone supplier/ contractor and/or operator)**
Professions	Operational co-ordinator, analysts	Operational co-ordinator, technical expert, operation and maintenance engineer, subsea engineer, etc.	Operational co-ordinator, technical expert, operation and maintenance engineer, subsea engineer, etc.	Control room operator/pilot
Temporal rhythms	Weeks and months (years)	Hours and days	Minutes	Seconds and minutes
Temporal horizons / what	Plans the operation based on historical data and information. Examines the data accumulated by the drones after docking by looking for anomalies and patterns in the data sets.	Firsthand analysis and evaluation of the accumulated data.	Executes the mission. Make sure that the operation is going according to plan. Gives orders to the pilots (e.g. zoom in here, go there).	Initiates the planned operation. Controls the drones (dependent on LoA). Handles alarms or unforeseen events that occurs during the operation.
Data	Docking	Non-critical docking and real-time data	Real-time data	Real-time critical data
Temporal coordination with artifacts (models)	Coordinate data sets, make models, run simulations, etc. Looks at long-term trends and place different types of data into a bigger context. E.g. run/ simulate the mission using a digital twin. Look for patterns and anomalies in large data sets, i.e. pipeline surveillance	Evaluates the quality of the accumulated data and perform analysis. Provide feedback to the coordinator.	Generates necessary models for the operators (e.g. map-layers) and/or evaluates real-time data.	Alarm handling and manual control if necessary for the operation.
Necessary functions	Data processing and management, mission planning system. Tags data	Mission planning system	Dashboard, communication, real-time plotting	Health monitoring system, dashboard, control and navigation, CCTV, communication, alarm/error system

4.1.3 Check and Report - a critical operation

If an unforeseen error occurs on the subsea facility, an alarm goes off, or a sensor breaks down can the control room operator send the fleet, one or a couple of underwater drones to check out what is going on. It will then collect the necessary information about the instruments/equipment's current state and report this to the control room. Using drones for these kinds of operations gives the control room quick clarification on the problem reported. Based on the information collected is it also possible to start planning maintenance or repair on the equipment if necessary, outside the standard inspection rounds. It is also a way to check if everything is as it should be.

This kind of operation will most likely be internally within the organization, but can also be ordered from external support functions. Check and report missions trumps all the two other work processes, as it is more critical. The CROs can redirect and reorganize the fleet as they see necessary to manage the error/alarm, and is responsible for placing the facility into a secure and operable state. The observation support center shall assist with domain knowledge.

In retrospect of such a mission must there be delivered a report from the control room and the operation and situation must be analyzed. This is something the system administrator is responsible for, and inspection must be planned if necessary.

Check and report missions can also be used to obtain complementary measurements, which is not a critical operation. The control room gets fixed measurements from a diversity of sensors and equipment placed on the template, but from time to time it will be necessary to complement them with other measurements and readings using the moving sensor platforms. It can also be used to fill gaps in the accumulated data from a fixed continuous monitoring mission or replace inclusive data. The additional data/measurements can be ordered from the functions outside the control room.

Table 4.4: Key temporal constructs for check and report operations.

	Data analysis center (outside control room)	**Support center**	**Observation support center (operator)**	**Control room (drone supplier/ contractor and/or operator)**
Professions	Domain experts, analysts, system administrator		Operational coordinator, domain expert (dependent on the situation/alarm), system administrator	Control room operator/pilot
Temporal rhythms	Months, years		Minutes	Seconds (and minutes)
Temporal horizons / what	Combines the accumulated readings with other data. Places orders on measurement readings. Analyses check and report missions to see if further inspection is needed, or to learn from the situation.		Observe the mission and give necessary guidance/information on how to handle the error. Verify situations in the field.	React on the alarm/error that has occurred. Reprioritize the fleet if necessary. Controls the UID(s) and fix the error if possible. Initiates the additional measurement reading.
Data	Docking		Real-time (critical) data	Real-time critical data
Temporal coordination with artifacts (models)	Analysis		Places work orders and note relevant measures	Responsible for setting the field back in a operational and secure condition.
Necessary functions	Mission planning system, data processing and management		CCTV, communication, dashboard	Health monitoring system, dashboard, control and navigation, CCTV, communication, alarm/error system

Data are transported to the control room via buoys providing 4G or fiber optic cables. Acoustic and optics are also used for communication with the drones from the control room. For each work process are the needs for data different, as some operations are more critical than others and require real-time crucial data. Having these different temporal rhythms gives a different understanding of trajectory and space for each of the three inspection operations. This can further be seen in Table 4.4, Table 4.3 and Table 4.2.

As seen in the tables does each of the inspection operations has different needs and functionalities, as well as a different understanding of time, space and data management. This affects the needs and surroundings of each operation. It should also be noticed that sensors and sensor platforms needed for each use-case will vary and that the stages of the field's lifetime also will have different needs for the sensor platforms. This was discussed in more detail in the specialization project but is an important factor to have in mind when thinking about the utilization of this control room.

4.2 Phase B: Analysis and definition

The analysis and definition phase consists of five steps, having multiple objectives and prerequisites. In this phase are the functions presented and allocated to humans and/or machines. The organizational design is also presented with two alternative concepts. Not all elements of this phase are included, as it is outside the problem statement.

The purpose of a control room is to provide the control room operators (CROs) the facilities they need to monitor and control a system. This is done via a human-to-machine interface (HMI), which enables a person to interact with a technical system. The HMI displays the processed data and allows the CROs to make changes to process parameters, as well as to develop, maintain and use accurate and up-to-date situational awareness of the current, recent past, and likely future state of the system. This includes interacting with the system quickly and efficiently under all plant conditions (EEMUA, 2019).

The HMI of the control room, as visualized in Figure 4.2, must be designed with regards to HFE: it must be intuitive for the user(s), unambiguous, consistent, have a simple design without unnecessary details, and be reliable (EEMUA, 2019). This can be achieved by only providing the necessary data and information for the given operation/task, in a way that does not create hazardous situations. Some of the functions needed in the HMI are presented in this section.

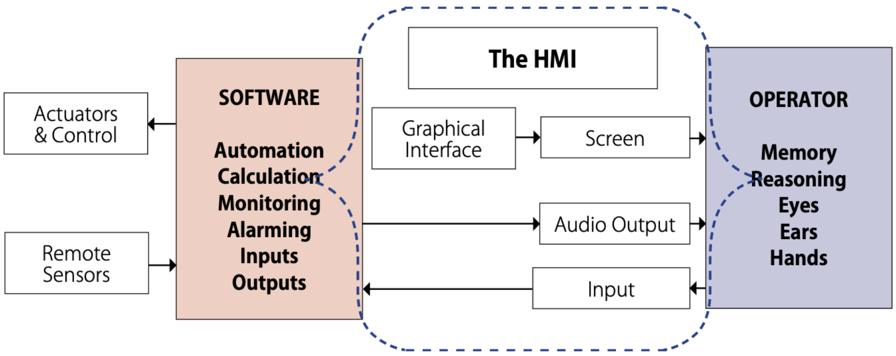

Figure 4.2: HMI: the sensory interface between operator and plant (EEMUA, 2019)

The more complex the operation, the closer you get to a control room. In this UID-control room case is autonomy a huge factor that molds the development and design of the room along with HMT. Finding the right balance when it comes to this, *and* include the operator in the process, is perhaps the biggest challenge in this project, as also mentioned by ID2 below:

> ID2: Autonomous operations have a degree of autonomy that can vary and it varies greatly with what communication one has available, what perception of

> sensors one has available, what automatic situation understanding. Balancing all this is very challenging when designing an autonomous system. And when I say autonomous system is the operator in there, so there is a control room because it does not have to be fully autonomous.

This brings us back to chapter 2, finding the right level of autonomy (LoA) for each machine in the system and for the given tasks/operations, as well as dynamic function allocation. The results from the interviews are a combination of vague wishes and specific design requirements. This mix of feedback perhaps substantiates the complexity of this case, but it also shows that the extensive allocation at this point in the design process may not be entirely expedient. This, as one will see, has an impact on the results presented and the thesis in its entirety.

As seen in the tables presented in section 4.1 will each use cases affect the performed tasks in the control room, resulting in different function/system needs for each operation as well as for the outside support functions. ID6 points out what is important for the control room in terms of data flow, and even though the control room for the UID-fleet is the main focus, plays the surroundings and ecosystem that it is a part of an important role, both in time and place, affecting the necessary functions and its allocation.

> ID6: I envisage a typical operating room, which is in the word, has the operational and secure handling of some real-time data in that connection if it is necessary in connection with the operation. Then I think it may not be natural that the control room is closely involved in it when you come afterward when you get the drones docked and get a lot more data than we can in real-time to start doing analyzes and connect and things like that, then I think it is not the control room that needs to perform that function, it can be done elsewhere

4.2.1 Step 2: Define system performance (functional analysis and description)

According to the goals and intentions of this thesis work was a functional analysis performed to gather wishes and needs on necessary technical functions/systems for this UID-control room. Using a qualitative method with interviews, as described in chapter 3, where relevant functions and needs obtained and further analyzed. This step presents the results of this analysis.

All interview objects were asked: *"Which/what functions/systems, in particular, is/are needed in such a UID-control room, to be able to develop an operational and scalable control room?"*. As the control room is the link between drones, docking stations, human operators, and IT systems needed in this case, was the question interpreted and answered differently among the participants. Their focus was often one part of the control room and not all elements, which was not unexpected based on their backgrounds, and was also a factor in getting a diversity among the participants. As mentioned in chapter 3 did the response to the questions, especially this one, vary a lot, where some interview objects listed up essential concrete specifications whereas others mentioned more vague wishes and/or told stories with relation to similar contexts. What was considered irrelevant of the data material was weeded out, either by shortening statements, deleting the text, or not assigned a code.

The overall principle in HFE is having a human center design (HCD) approach, which means that the system(s) and its functions in the control room must be adapted to the humans, not adapting the human to the system. Several principles within HCD must be adhered to when designing a system and they all have requirements that need to be fulfilled. One of them is consistency in the system. ID7 points to: "If you have multiple devices from multiple companies which are controlled differently or visualized in a different way, so is the human being bad at it. There has to be consistency. There has to be an equal way of visualizing the state and an equal way of interacting, otherwise, you can't keep up and suddenly make a mistake". This is an important factor to keep in mind, as one of the biggest challenges with this type of control room is proprietary solutions, where each drone supplier is having its own systems and lacks standardization.

Since there are several systems involved in this control room that needs to be seen in context became it natural to divide the functions listed up by the interview objects into two main categories: technical control and data. Technical control refers to control, management, and observation of the drone and docking station from the control room, while data focuses on data handling and processing of the data accumulated by the drones and transferred in between the drones, docking station, and control room. This sectioning, or equivalent, was also listed by the interviewees, as it is important to distinguish between control and data management when multiple systems are interacting.

Some of the functions presented are necessary for the CROs in the control room to handle critical situations, others are needed by the support centers outside the control room, but that has a link to the control room, as seen in Table 4.4, Table 4.3 and Table 4.2. Some of the functions/systems also have a dual role, meaning that they are important in several stages in the operation, but with different time horizons and criticality, as also seen in the operation tables.

Technical control, management and observation

This part focuses on the technical functions needed in the control room. They are aimed at the control of the drones, as they are the foundation of the development of the UID-control room. Autonomy plays a central role here and many of the functions are necessary to gather the necessary situational awareness for managing the three inspection operations.

These functions/systems are foundational capabilities that must be in place for the control room to work after its intentions, along with necessary infrastructure and other basic functions.

- **Picture and camera surveillance (CCTV)**
  As the drones are operating in an environment far away from the control room and its operators is it important to have picture or camera surveillance on the drones. This function provides "eyes" at the scene and gives some of the necessary situational awareness for the operators.

  The camera function has two functionalities: one for the control room and the second for the support functions outside the control room. For the drone operators will a live feed of the operation be useful for manual control of the drones, e.g. for controlling an arm on a ROV that is turning a valve, as well as making sure that everything is going according to plan and that safety is taken care of. However, getting this video feed in real-time has its challenges. Communication and data transfer is weakened and restricted under water, and the quality of the video or pictures will therefore be limited if it is even possible to transfer it to the control room in real-time. It might be possible to transfer low-quality/frequency video for drones operating without an umbilical in some areas close to infrastructure that provides this communication. High-resolution imaging will be possible to obtain when the drones are cabled to the docking station(s).

Secondly, the video stream(s) can be used as an information/data source after the mission is completed by the functions outside the control room. After the drone is docked it can download high-resolution data that it has taken on its mission. This can then be processed by the personnel outside the control room, by trying to find abnormalities or detect changes.

- **Communication**
  Communication is key, and several communication links need to be established for this UID-control room - both horizontally and vertically. However, communication under water presents its difficulties because of the limited bandwidth. Communication can be transferred through acoustics, optics, satellite links, or a direct line. Vertical communication is the easiest link to establish. This is hierarchical communication with the control room on top/in center, as seen simplified in **??**.

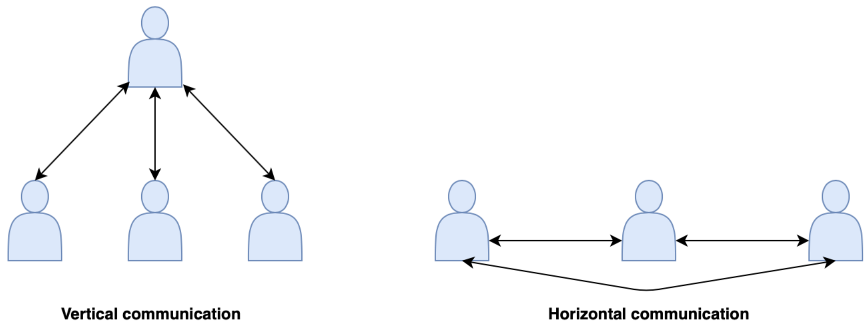

Figure 4.3: Illustration of the two lines of communication, vertically and horizontally. These two can be integrated.

First of all, must it be possible to communicate with the drones and docking stations from the control room through a set of commands (e.g. start, stop, continue), predefined or in the moment (e.g. live programming). This communication link is important for mission execution and data transfer. Secondly, there should be communication between the drones and docking stations. This especially during the docking process when connecting the drone to the station. Here are authentication of the drone and correct connection to the plate important factors. This communication will be performed digitally and there must be developed systems for it.

Thirdly, must it be possible to communicate between the control room and other personnel. How this will work in detail, is dependent on the organizational structure of the room (two examples are presented in subsection 4.2.4) and other actors involved, in addition to the combination of people and expertise in the room and outside. Use cases and tasks performed will also have an effect on how and what is communicated. Information will have different degrees of criticality and how it is communicated should be dependent on that, as well as to whom. It can be oral or written, using email, teams, telephone, Teams, etc. This must be defined early in the design phase.

> ID4: You must be able to communicate with various subcontractors or system owners who have support systems that are part of the operation

Horizontal communication is communication in-between the same grouping. This can be between drones, docking stations, or control rooms. Establishing communication between control rooms or other companies involved in the operation can be human-centered, meaning that it can be "ordinary" communication between people. Communication between drones, however, will be much more complex to establish. Horizontal communication between drones will be useful when having a fleet of drones operating together as they can collaborate to execute the mission. It will make it possible for the drones to utilize each other's resources and equipment. For example, will this make it possible for one drone to provide light and cameras, while another one is turning a valve. This without (special) interaction from the control room operators.

However, it must also be possible for the drones to operate without communication to the control room or docking station. Most likely will there not be enough bandwidth for communication for all drones (at the same time), or that it is being sent on a mission outside the "marked" area. This is related to the level of autonomy given to the UID, and routines for handling such cases must be developed.

- **Control and navigation**
An important function in the control room will be to control and navigate the drones. This can be done manually or automatically and is dependent on the level of autonomy (LoA) given to the respective drones used in the operation.

  Regardless of LoA must it be possible to manually control the drones from the control room. This is a safety mechanism; if something goes wrong with the drone or an unforeseen event happens, it must be possible to turn off the autonomy and manually control and navigate the drone to a safe zone or put the facility back into a safe condition.

  Today are ROVs controlled using joysticks and two pilots for each ROV. AUVs are controlled through software. There must be a solution for the joystick navigation in the room (that is ergonomically adapted) so that if it is needed can the CRO intervene and manually control the drone(s). There also exist other technologies that can be used for controlling drones, such as AR, VR, and hololens. However, VR can be experienced as very demanding over time, as the pilots can become seasick or dizzy. This can also apply to other tools and a combination of different tools for control management should therefore be available in the control room.

  In the interviews, participants mentioned that navigation must be easy, and as much as possible of control and navigation should be manageable by the drone itself using autonomy. The navigation system must also be intuitive, flexible, easy to use, adaptable and responsive.

- **Mission management system**
Having a mission management system that has the overall control of the operation is essential. The system should include several important functions listed below. The mission management system is where missions are planned and are usually used outside the control room. However, are the missions executed by the CROs from the control room and they should also have access to several functions that the system consists of.

  - **Mission planning tool:** The must be a tool for mission planning where the operation is described in detail. This system must tell something about how many drones should be included in the operation and which type of drones, what tasks they shall perform and why, which staff to include, the time it should take, possible risks, etc.

    For planned inspection and fixed continuous monitoring operations should the planning phase take place outside the control room. For check and report missions, which are critical operations, should the planning tool be available in the control room (or the observation support room/center), so that the fleet can easily be programmed to handle the unexpected operation/task.

  - **Status information/progress report:** There must be a function for giving status information/progress on missions. A screen presenting a timeline of the operation and wherein the operation one is, as well as which type of operation it is. It should also include an overview picture of the area the drone operates in.

– **Logging and reporting:** Everything must be logged and reported for further use. This is an important function for traceability in retrospect, as well as for learning and error detection purposes.

> ID2: For each mission should a report be delivered. The report must distinguish between when things go as expected and when things do not. If the mission went according to plan can the report be delivered afterward, and this process can probably be digitized as reports can be generated automatically. However, when things do not go as expected, one might have to report the outcome right away, depending on how important it is.

How this report should be delivered and organized is up to the operator or supplier, but a standardized report template could be nice to have so that data can be easily retrieved regardless of which companies have been involved in the operation.

– **Operating statistics:**

> ID3: It might be necessary to collect data on the drones' history. For some of these robots, it may be a good idea to check if they have any operating statistics, e.g. how long has it been operating, what has happened and when, and what has been done with it. These statistics can be useful in risk assessments, but they can also provide an understanding of how the drone works.

Operating statistics is important as it works as a digital patient journal for the drone, containing historical data on the drone's previous missions and/or faults, being an element of the necessary situational awareness needed. For example, knowing that the arm of ROV X is a little bit defective can be crucial in an operation as they often involve small margins. It is also useful for historical purposes, as it can be used for maintenance and analysis of wrong modes.

- **Autonomy for control of the fleet**
The greatest uncertainty and predictability in this type of control room and the drones themselves is the autonomy of the drones. Autonomy is an essential function for fleet management of the UIDs, but is something that is still in the development phase and needs to be given trust. Many factors must be in place and evaluated before the drones can operate on their own, such as trust and maturity. The LoA will vary for each operation (use case) and task(s), and this function must account and facilitate for that as ID2 says. That the need for autonomy in different levels affects the operations, makes the need for optimized HMT essential, and allocation of the functions complex, especially in this part of the design process and in this autonomy function.

> ID2: When it comes to what should be available, then in a low-risk operation it may be typical that the drone asks the operator if it can start, and then the operator should have some information base that makes it a point to ask the operator at all. Then, for example, the drone can say something about its status, it can tell about its mission, what it intends to do, and then you must have some key information about how long it will take, the status is all green on the drone, if it has enough battery, it has connected what it needs and all that. While on routine missions, scheduled missions,

> it may be that the drone may not need to ask at all, because it is planned to the smallest detail.

When it comes to controlling the UIDs will autonomy be a great tool for movement and navigation, and as there are few(er) risks under water should it be possible to just command the drones to move from A to B without manual control. Having the drone follow a fixed pattern e.g. follow beacons or pipelines, as in fixed continuous monitoring, is something that the drone is easily be entrusted to do alone.

The area where the drones are placed can be divided into different zones, where some areas are green and others red, meaning that in the green zones can the drone move/control itself and the operation as there are small risks. In the red areas are there higher risks and the drones must/should be if not manually controlled, at least observed more closely. It must be possible to send easy communication commands from the room to the drone, or another way around when something unexpected happens or the drone arrives at its destination and asks if it can do something/the next step of the task.

> ID1: In areas where the drone(s) can do damage must you be able to have close supervision - at least in the beginning until you can trust the system(s). Must be able to override it and have continuous real-time data.

Autonomy is a function that will gradually evolve and be risk-dependent. There are also some ethical aspects that need to be considered when giving away the main control from humans to machines, as mentioned by ID7:

> ID7: ... then we enter into an ethical discussion with what roles should the machines have, do we allow the machine to operate autonomously, and make decisions on our behalf, or do we not?... Do we accept that a drone that is programmed to do a job and when it should return it does not come back again, and we do not know what has happened, whether the drone has done its job or not?

The autonomy function/system on the drone must then include a risk assessment and safe job analysis (SJA).

- **Permit to work system** [2]

A permit-to-work (PTW) system should be included in the control room as we are talking about a fleet of drones. When having several groups of drones operating in the same area, it is important to know where they are and what they are doing, but most importantly, to make sure that they do not interact in a way that is unsafe for either operations or the environment. Tasks activated or deactivated are controlled by the control room, and having a PTW system will give them the necessary dynamic real-time awareness of what is going on at any time.

Using this system can be useful for gathering extra information and data from other sources in the area, as mentioned by ID8. It can also give an indication of how the fleet is utilized, which drones/fleets are free, and an overview of work in progress.

> ID8: If we for example are working in an area with an ROV and a USV comes into the area and is going to do something and it, for example, has a sonar or a camera that is relevant to us, then we can easily pull it into our operation.

This is something that makes this UID-control room interesting - that drones can exploit each other and there are systems for this.

[2] Norwegian: Arbeidstillatelser (AT)

Data

There are huge amounts of data collected and processed in this UID-control room. Some data are important in real-time, other data are not necessary needed in the moment, but for predictions, historical aspects, or planning inspection. Some data is necessary for the pilot, other for the observers or domain experts. These needs are visualized in Table 4.4, Table 4.3, Table 4.2, and summarized in Table 4.5. How the data are distributed and in which time, is one of the complex tasks that must be answered and it is also dependent on the organizational structure. In any case, information must become knowledge as fast/soon as possible.

Table 4.5: Overview of which stakeholders handles which data

Data	**Docking**	**Real-time**
Critical	-	Control room
Non-critical	Others	Observation room/center

As there are limitations on bandwidth under water cannot all data be transferred and processed in real-time (unless the drones are cabled to the docking station). A priority of transferred data from the drones must therefore be made, as some data are more crucial than others. The operation room should according to ID6 have the operational and secure handling of the real-time data that is necessary in connection with the operation, this is also seen in the operation tables.

> ID6: I think it may not be natural that the control room is so closely involved in what comes afterward when the drones are docked and we get a lot more data than we can in real-time. Doing analysis and connecting [data] and things like that, is a function I think the control room does not need to exercise, it can be done elsewhere.
>
> We know, for example, that when the drone is out of the dock, there is limited data capacity on networks and all that. Then it must prioritize what is needed in real-time, and then the other comes in afterward when you can have the opportunity to record much more data, different types of data, and other types of communication than what happens in real-time.
>
> [The drone] can record a lot of other types of data that are not relevant for how it should maneuver, and it is data that I think ok, they now go into the internal storage of the drone, and then it swims for an hour or a day or two, and then you can upload that data once you have docked the drone and got another infrastructure.

As it is today can you get optical signals up to 400 meters, but these are reasonably low-resolution video signals. Beyond that it goes on acoustic signal for a couple of kilometers, getting only kilobits of data, meaning that one hardly gets to know that the drone is alive - you do not know exactly where it is or what it does. After that, there is an end to contact. Basing the system only on real-time data will not be possible with the available communication because of the conditions underwater, but it will not be robust either, as pointed to by ID4.

> ID4: It will not be possible to get everything in real-time in this system. This whole problem here consists of a set of situations where you have a long tail, where you have a number of situations that can arise that means that you do

> not have full bandwidth. I think no one is going to make a system based on real-time streams all the time, it will be very un-robust and one must rely on acoustics .... the system must consist of both (real-time and docket data), both high and real-time capability...

The data streams must therefore be prioritized and only necessary data should be transferred in real-time, the rest can wait, as ID5 points out:

> ID5: In other words, those safety-critical things and housekeeping data must be kept at all times, while the scientific benefits are often such things that can wait.

When it yields for non-critical data can these be "dumped" in the docking station after the end of the mission or when charging during the mission tasks. This is typically data that needs to be processed and has other temporal rhythms than the control room. This is also something that the interview objects have stated:

> ID1: ... if the drone is going out on a mission to check something [non-critical], then it can send what it has when it comes back to the charging plate. ... Yes, I think it can be fine to upload the data afterward, as long as the drone can not do any harm, then you may not need real-time data.

> ID2: High-resolution video of the mission is typically something that can be downloaded afterward.

> ID5: ...it is clear that images of what they will possibly inspect, if it is a routine task, is something they can "dump" when it is docked. So this is very much dependent on the nature of the mission and the vessel to be steered.

Data governance with its principles must be followed here. The Data Governance Institute defines data governance as "a system of decision rights and accountabilities for information-related processes, executed according to agreed-upon models which describe who can take what actions with what information, and when, under what circumstances, using what methods." (Olavsrud, 2021), and it defines roles, responsibilities, and processes. (EOL IT Services, 2018) presents five principles that must be in place for ensuring effective implementation: accountability, standardized rules and regulations, data stewardship, data quality standards, and transparency. These must also be considered in this case, but are not gone into detail here.

The huge amount of collected data from the drones will be transferred in real-time or when docking, depending on its criticality (as seen in Table 4.5). For the control room is it important to extract the sensitive data so that the operation(s)/task(s) can be carefully executed. This data must be visualized in a good way, be easy to access, and be informative for the operation. This requires a good user interface. The necessary functions/systems pointed out by the interview objects when it comes to processing and management of the data, are the following:

- **Data processing, handling and collection**

  - **Processing and filtering of data**: The drones perform different inspection missions (as described in section 4.1) where they collect a diversity of data that needs to be processed and filtered. Most of the data that have been processed are accumulated by the drones as well as produced by the drones themselves. This can be status data on the drone, video streams, readings of CO_2, etc.

There are three ways of processing and filtering the accumulated data: One option is that the drone can process and filter the data by itself, however, this takes up much of the battery capacity. Secondly, can the docking station process the data collected by the drone when it docks (or is cabled together), as mentioned by ID9. Lastly, the can data be processed when it arrives at the control room (or is routed to another support center).

> ID9: You can also imagine that you have a data processing unit in the docking station. The robot collects data, and data processing costs energy and space, so it just downloads it to the docking station where there is a data processing unit. Then you choose what it is that must be passed on to land. ... I think the direction you want to go in is that you put more and more data processing down in the UID/dock and then minimize the amount of data that you need to transfer from the robot.

The data routed to the control room should be relevant for the operation(s), meaning that essential data should be filtered out before it is placed in the dashboard, as ID5 mentions. However, the data filtered out for the CROs might be wanted in analysis and simulations afterward.

> ID5: ... instead of getting 1000 data points or parameters every minute, you only see the 50 that are actually relevant. It is about filtering out the essential data, but also presenting it in a useful way ...

A lot of the collected data can be processed and filtered automatically. Using technologies such as artificial intelligence (AI) and machine learning (ML) can the drones be trained up to evaluate situations themselves and reduce manual work for humans. This will especially be important when performing missions with drones on higher LoA.

– **Routing of data**: The data must be routed correctly to the drone, person, or room that needs it.

> ID6: This is where setting up this system comes into play, and not least what goes on multidisciplinary approaches, including hardware, networks, and plugs up to the logical layers of this routing and security of data, and then the next over to begin interpreting them. Then there is logical routing over there again, and ownership of how the payloads and formats look, how it is packaged, what APIs, power, etc., and retrieve all that. It will be a huge architectural job that must be done ...

As ID6 mentions is this a huge architectural job that must be done while having interoperability and ensure safety (for both the operation and data access).

– **Storage and back-up**: There must exist a solution for the storage of data and a routine for which data should be stored (some data are might not necessary to keep). There should also exist a backup of this data. This is a function that is not needed in the control room but is important for the whole ecosystem, providing necessary additional information in situations, e.g. operational statistics.

– **Real time analytics**: ID2 mentions that data on-demand is something that should be implemented in the control room, having both on-demand real-time analytics and continuous real-time analytics.

According to Techopedia, 2021 is the first one a type of data provision where users get a single real-time view of the data by initiating a user event, and the data becomes available to analysts as soon as it is created. The second, continuous real-time analytics, is when data are continually refreshed without the human refreshing or interact with the system for it to be requested. They both need IT architectures that can effectively bring data from where it is created into a greater software architecture and deliver it to an end-user who may be using an entirely different set of software programs (Techopedia, 2021).

> ID2: There is something called data on demand. Being able to collect enough data to get a situational understanding and then you can rather collect more data like that specifically when you need it, I think will be important. A concrete example that maybe you give the operators many low-resolution images first, and then the operator can choose from those images what it really wants to look at, instead of having to wait a while for downloaded high-resolution data.

ID2 also mentions that this data-analysis tool can be great for situational awareness and understanding. Real-time analytics is a function that is very useful to have in the control room, as it provides the newest data without the CROs needing to manually refresh the data stream, which can be crucial in a critical operation.

- **Visualization in dashboard**

  An important function in the control room and the HMI is the dashboard that visualizes the data. This dashboard contains all important information that is needed to perform the inspection operations safely and securely and should be developed very user-friendly and intuitively for the CROs. This will be presented on the many screens placed in the control room.

  EEMUA201 states that there are two main uses of screens and panels in the control room, and that is for monitoring and work. They are used to display information that allows the CRO to keep track of what is happening (monitoring) and actively engage with the system using input devices (work) (EEMUA, 2019). The main purpose of the dashboard is to present the measurements and readings from the sensor platforms that are needed for these two purposes, as well as having pictures/video of the area or other graphics related to the mission(s). It should also contain maps, position, status on housekeeping data, etc.

  Some of the data presented should be color-coded. This will make it easy for the CROs to understand if the readings are good, medium, or bad. It can also be a good tool for minimizing human error as the operator does not need to remember all values/intervals for every measurement. However, the colors used must be logical, but readable for a color-blind person (e.g. avoid red and green). Usage of different symbols can also be useful in the data visualization (e.g. use circles to present docking stations, triangle as ROVs, and squares as AUVs in maps). It is important to have this in mind when designing the system, and more on this can be found in EEMUA201 and ISO 11064.

  The dashboard should also contain information about the vehicles' speed, angle, position, location relative to other devices, etc., as well as sensor data and environmental data, such as weather, wind, time current, and weather forecast.

  From a human center design view should one also visualize the data in the best possible way for the human. It is difficult to understand what is going on if one has too many screens with too much information and several camera views and so on.

  > ID5: What may also be appropriate is to create a visualization program/app that brings out the important information, preferably to pro-

duce the graphic, with color codes, images, etc. that make it easy for the operators, but also the data owner to see what is happening. So instead of getting 1000 data points or parameters to each minute, you can see the 50 that are actually relevant.

- **Health monitoring system**
  The health monitoring system is probably the most important system for the control room operators or pilots, as it presents the status and operation of each of the essential components (such as sensors, drones, and docking stations in this case). Its objective is to monitor the condition of the system at all times by presenting data such as position/location, battery level, and sensor failure - also known as housekeeping data. If the system catches an abnormality it is supposed to communicate it by raising an alarm or implement a number of procedures.

  The system should contain key information on the equipment at all times, presenting its status in the dashboard. The housekeeping data is marked as critical for the operators in the control room and is a priority to communicate out from the drone to shore in real-time. The data collected here often forms the basis for a check and report assignment, as it tells something about the condition of the sensor platforms and other subsea equipment monitored in the control room.

- **Meta data/tags and geospatial data**
  It is necessary to store the data with the right amount of metadata (data about the data). Metadata is typically arranged so that it is searchable in a database, having a tag. This makes it possible (and easy) to go back and read the data and understand what has happened, as it tells something about the position and content of the data.

  Date and time are typical metadata, but here is also geo-referenced data important. Stock and Guesgen (2016) defines geo-referenced data, also known as geospatial data, as the following: "Geospatial data is data about objects, events, or phenomena that have a location on the surface of the earth.". It can be static or dynamic, dependent on whether the object is in motion or not. In this case, will the docking stations have static geospatial data as they are located at a specific location at all times, whereas the drones will provide dynamic data, as they are mobile and moving around. The data is essential as it combines location information, attributes information, and often also temporal information (Stock and Guesgen, 2016).

  This data, including other metadata, have several purposes in the control room and its outside functions, as it can say something about where an event has happened, be used as a reference for other data or objects, and historical purposes. Giving the data enough metadata and geospatial data can also make the use of digital twins and other simulation tools efficient and useful.

- **Automatic Identification System (AIS) and maps**
  Maps should be a part of the dashboard and these should be updated in real-time (if possible) with the position of the drones - just like an AIS system for ships, but for drones. A AIS, Automatic Identification System, is an automatic tracking system that gives a continuous overview of the ship traffic (using satellite data), by sending out the ships' identification, position, speed, direction, etc. It presents the data on a map, making it possible to have an overview of the ship traffic in a given area.

  Having a system similar to AIS for drones can make it possible to track all drones in a given area. It will also give the field operators an overview of the drones' locations in addition to supplier company when the drone-suppliers are controlling the fleet (proprietary rooms), making it possible to reach out to a given company for getting a job done. The system can then give the information the field operator or customer needs to contact the drone supplier or pilots. It should also be possible to use the maps in the system together with other data/information and map-layers.

Other input

In addition to systems and functions related to technical control and data management does the control room also needs the following functions:

- **Alarms and error reporting system**
  Alarms are a critical part of the HMI and a system for error reporting must be in place at all times and be easy to manage by the control room operators. The system must evaluate readings and situations, and decide whether it should raise an alarm, change color, present a pop-up window with a message, or something else. Either way, it must catch the operator's attention.

  The alarm system is an HFE issue as it must be designed for humans from the start, as it is more challenging to adapt it for humans later on. The system should follow a three-step approach: first finding out that you have a problem, then decide what to do and take action, and lastly, check and manage what you have done (Anderson, 2021a).

  > ID3: When it comes to deviations, you must have thought it through in advance: what deviations are you having and what should you do when they occur. Deviations for drones are typical sensors failure, it does not happen exactly as planned, you get a collision, or that things do not happen at all, in addition to the fact that one can get physical errors as that it fails, falls, or gets destroyed. ... It is then important that you get good alarms.

  The alarm system is one of the most important systems for the control room as it tells whether the CRO(s) must interact with the drone(s) and manually control it/them, or that the facility is in a critical situation. "An alarm can be defined as an audible or visual indication of an equipment malfunction, process deviation, or abnormal condition requiring a response by a person. A key point is that every alarm should have a clearly defined operator response." (Anderson, 2021a). It is important to balance the error reporting system because humans cannot deal with more than a maximum of 6-8 serious alarms in an hour. The alarms must also be understandable and clear for the operator because it will be difficult to understand what is happening if there are too many (unclear) alarms going off at once. Another aspect to consider, pointed out by ID2, are false positive and false negative alarms - where should the line go and how much error tolerance can one accept? An alarm philosophy that ensures good alarms, and not too many and in a prioritized order, should therefore be developed.

  > ID2: A false positive is that the computer says "look here, here is corrosion", but then there is no corrosion. While a false negative is actually worse, because then the computer does not think that there is corrosion there, but then there is actually corrosion. So where to balance it in such a control room perspective is difficult. Because if you are to avoid false negatives, that the computer does not say that there is corrosion, then there will quickly be a lot of false positives. So balancing there is important and difficult.

This system is extremely important when the drones are given a higher LoA as the drones are no longer (fully) dependent on the operator and tracked/monitored one-to-one. A potential challenge with the alarms is proprietary alarms. That each drone supplier has implemented its own alarm system on the drone(s) that does not correlate with other companies' systems. As mentioned by ID7 can this be a problem for the operators - that similar alarms have different messages, and they can create an even more dangerous situation.

> ID7: And then we are talking about alarms. Is that a point? Can the drones tell and inform that 'now am I low on battery' or 'now I've lost control, I do not know where I'm going'? So alarms are not really a very good tool if there are too many of them. The alarm must be real and it must tell you something - give understandable messages. If it is much different, that you get a message from a drone from a company, and then you get a different message from another company, then that is not the way to do it, you have to harmonize it into a common platform.

Requirements for alarms, including prioritization, should be determined in accordance with EEMUA publication 191: Alarm systems – a guide to design, management, and procurement (EEMUA, 2019).

- **Configuration management system:**
  This system is for technical and administrative activities. It deals with the management of changes in software and other tools that are needed. It is also useful for knowing which drones one has and what equipment they have and can supplement it with operational statistics.

  > ID5: I think it is important to have configuration control. That you have control over what you have and do not have of equipment. By configuration control, I mean that one has an overview and control of exactly the condition that your product is in exactly when you use it.

- **Security and infrastructure**
  Some interview objects have mentioned security as an important factor, which is a founding capability. This yields for both cyber-security as well as security on the site where the drones operate. The technical aspect around security is assumed good in this thesis, however, it is important that the drones are authenticated when docking and that data streams are secured.

  The necessary infrastructure at the site and in the control room is also assumed in this thesis. It is however important that the necessary infrastructure on both equipment and IT are in place and hardware and software are in place.

4.2.2 Step 3: Allocate functions to humans and/or machines

Research question one (RQ1) focuses on which functions/systems are necessary in/for the control room and especially which are aimed at machines and humans. As step 2 answered which functions are needed will this step try to allocate the functions between humans and machines. Notice that some functions/systems can be delegated to both parties because much of the functions are dependent on autonomy, IT systems, and the type of operation.

Allocating functions (dynamically) between man and machine, is as mentioned earlier, a challenging task, especially at this early point in the design process where we are just talking about the theoretical approach of the design and allocation of functions based on this. In chapter 2 we saw that humans and machines have different performance characteristics and that machines can have different levels of autonomy, and these factors affect the allocation. This is a huge dilemma in human-center-design and human factors engineering, as one must define what must take care of then when it comes to controlling and taking care of the interaction between man and technology, man and drone, and man and robot. It is all about meaningful human control, keeping the human in the loop and at the human's premises.

The use-cases in this thesis show that the allocation of functions in this control room will vary a lot dependent on the operation and its tasks - which demands a dynamic allocation. Going into details in each operation/work process we see that they all have different needs and will depend greatly on HMT now and in the future when the technology is developed further, and that the functions cannot be delegated to only one part of the system alone. Looking at the work processes we also see that the systems must be designed with great flexibility and be scalable according to the needs in each of the use-cases. If it cannot do so, will the system not be optimized and value creation will not match the resources needed.

Delegating functions is complex because it is dependent on autonomy and its development, as well as good IT systems for data management and communication. ISO 11064-1 clearly states that the functions should be allocated in a way that creates jobs that are challenging, interesting, and satisfying, as well as meets safety and other requirements. When it comes to delegating the functions presented above requires most of them collaboration between humans *and* machines, as they are dependent on the level of autonomy that varies for each task. Others are dependent on good IT systems that can process the accumulated data and route them to the right users. The functions are therefore not delegated directly to one part, but are looked at in a perspective that separates human and machine, based on necessities, characteristics, development, and competence in a dynamic allocation.

The interview objects did not talk about the need for dynamic allocation directly during the interviews and the student did not ask about it directly either, as the need for dynamic allocation was discovered and clarified later in the semester/as the thesis took form and the material analyzed. This is a good example of how the landscape can change during a qualitative study, and the focus evolves in a different direction than first planned. Things are dynamic and one cannot plan everything in advance. This is also what we see in the assignment of functions in the thesis. Regardless, the material shows that some interview objects touched on the need for dynamic allocation indirectly. Most of the participants talked about static allocation, or that the drones needed to ask the CRO(s) for permission to do X during the mission, but apart from that operated on a high level of autonomy. ID2 however, is the one that talked most (directly) about the need for different degrees of autonomy during the operation, not just for a type of operation.

> ID2: So what functions yes. So you have it with control and data analysis, and then there is the fact that if that drone has a very high degree of autonomy, the degree of autonomy will typically vary through an operation. It will not just be the case that you just stamp a vessel with the fact that this and that have this and that degree of autonomy.

This quote does not say anything directly about how the functions should be delegated, but it states that it will be dependent on autonomy.

The goal is to ensure optimization of operations by using the machines on our behalf - and the functions must therefore be allocated accordingly. ID7 point out so nicely the following, which is an important problem statement in this case:

> ID7: Is it just one drone that is controlled and that goes back and forth completely alone and is docked once a day or week, then it is not certain that you need so much control other than a person who ensures it, that can check on the drone from time to time. But if you are going to have 150 drones that run continuously in many fields with different degrees of autonomy, where there may be some you have to control manually in some cases, while some go completely by themselves. Then you have to go more closely into what the person should perform, and scale the control room in accordance with those needs. What interactions do you need (between man and machine)? What management and monitoring activities?

This is exactly what separates this control room from a "regular" control room that only operates with one drone at a time. This is also something that makes the allocation of functions challenging by trying to find the right balance between humans and machines, as well as ensure scalability and flexibility. Adding autonomy to the drones imposes new needs that the technologists must understand and design according to since autonomy alone is not the solution, but the optimization of human-machine-teaming (HMT) is. The complexity of the operation and human authority stands strong. With high complexity, risk and scope will more forces be required to keep the human being in control, as control presupposes total authority and the possibility of being able to intervene in what is necessary. The system must therefore be adapted for this - for the human to be able to intervene as well as understand when it is time to intervene.

Machine

Robots/machines are better at repetitive, slavish, and static tasks than humans. Allocating tasks to machines requires trust in the system(s), good risk evaluations, and safety controls. In this UID-control room is there no doubt that autonomy will be one of the major functions that will present challenges and opportunities, and will affect both drone control and data management.

For this control room to be able to work must some (higher) degree of LoA be implemented and used on the drones, as we are talking about a lot of drones in this fleet. This will result in the drones getting more responsibility and tasks to perform on their own, given that safety is taken care of. When looking at the three inspection work operations that the drones are set to do: planned inspection, check and report, and continuous fixed monitoring, can the drones to some extent manage themselves. Fixed monitoring is based on autonomy and that the drones just follow a fixed pattern/grid and take measurements that do not involve interaction with the equipment. This can be an AUV inspecting a pipeline for corrosion, leakages, etc. The operation is predefined and can happen quietly in the background. For planned inspection, is this also a mission where the drone can control itself, but it might be necessary to manually control some parts, depending on the tasks in the operation, or give active commands to the drones from the control room. Check and report missions can have the drone automatically transporting it to the site where there is reported an error or default, but will probably need more human interaction to confirm or understand what has happened. So essentially, is driving from A to B something it can do itself and is, therefore, a function that can be delegated to the machines.

Delegating the steering/control functions to the drone themselves, will in most cases be safe (enough). How much interaction the drones have with the CROs along the way will be dependent on the mission type (use-case) and risks. ID9 played a bit with the idea that it will be a little like a lawnmower robot or a vacuum cleaner robot that is set to do something predefined and easy, and then it just happens on its own, and the CROs just acts as a supervisor and facilitates every once in a while. However, will this be risk-dependent and the idea from ID9 will probably work fine on fixed monitoring and IEM missions. When it comes to physical interaction with the equipment or unsafe zones will there most likely be a need for more human interaction. This supports the claim that there is a need for dynamic allocation.

As the control room generates a lot of data will a challenge bee to handle the huge amount of data. Using machines to process the accumulated data automatically will be a useful tool, as it is something that the machines are good at, giving room for humans to do more "exciting" tasks. By using AI and ML can the software be trained to detect changes so that the control room operators or other support functions do not need to e.g. look at hours of video to investigate if there is corrosion in a pipe, but instead they get a warning that there is a possible deviation, and can then go in and investigate the case further. This autonomous change detection function will only report the interesting data points to the control room, as mentioned by ID9.

> ID9: It is just the interesting data points that should be reported to the control room. This is how it should be - minimal manual work afterward to assess. ... What I think is the right way of thinking is three words: Autonomous change detection. It's not just data collection, what you should look for are changes. So if you then have an autonomous system that every week follows a pipeline and inspects it and it is only changes that are interesting to report and it is the same as last time, then it is not interesting and then a person does not have to deal with it at all.

Other tasks that the machines can do in this control room are to calculate and update parameters and values, as in real-time analytics, and ensure that monitoring and alarming works well and that the system is designed for the human.

Human

Unlike machines are humans not suitable for routine monitoring and repetitive tasks. However, they are better at tasks that require adaption, integration, and generalizations. Humans are planners and strategists. For the functions in this control room will the humans mainly have a supervisory role, but some direct interactions with the drones will be necessary. This because humans are in charge and have the overall responsibility for the ecosystem consisting of the technical equipment in addition to the environment at sea where the operations take place.

A lot of the functions where humans have responsibility are placed outside the control room, but is important for the entirety of the operations. These are the mission planning functions and activities related to the post-processing of mission data. When it yields for the human functions in the control room are they related to the human's abilities and competence. They are mainly about how good the person/CRO is at getting to grips with and understanding the situation when the need for human control arises, as well as providing human capabilities such as eyes, ears, and memory.

One of the dilemmas in HFE is *the irony of automation*. The term refers to "a set of unintended consequences as a result of automation, that could detrimentally affect human performance on critical tasks. Automation might increase human performance issues, rather than eliminate them." (Anderson, 2021c). Meaning that when the system goes by itself and is reliable, and then fails and expects the human to intervene, then the human is not capable of it, because it does not know what is happening. Automation of easy parts of the task then makes the difficult parts of the human operator's task more difficult (Bainbridge, 1983).

Even though we want to automate and digitalize as much as possible of the tasks in the control room will there always be a scenario where the system fails regardless of how "bulletproof" it is. The system designers are humans too and not all tasks will be possible to design away. These tasks might not comprise a cohesive, meaningful, or satisfying job role, which is important in HFE. Trying to avoid this, should tasks be dynamically allocated between man and machine, but the human often ends up with a monitoring role - which is not one of the humans biggest strengths (over long duration). This is a huge challenge, getting humans and machines to work together, and then to rely on the human(s) to take over if the system fails. It comes with its challenges and is not as simple as one might think.

One of the most complex questions to answer when working with autonomous systems is how to maintain situational awareness and keep the human in the loop. Robots do not have the same characteristics and abilities as humans, and trying to give the robots some of the understanding is difficult, as many of the interview objects identified:

> ID4: I think what is needed is obviously to have system monitoring on the robot, as well as a good camera set up so that one manages, based on the camera setup, to understand the surroundings in the same way as a diver does.
>
> ID5: And then it is always the case that if you put a robot to do the slavish, boring, and repetitive tasks, then that robot can always fail. Then it is important that the operator can easily jump in and take over that task. So it is important not to automate everything because then you can automate away some of the operator(s) basic understanding. So it is important that no matter what you automate and put away, you retain the expertise of the operator team so that they can jump in and take over if necessary. ... But it is of course a challenge and we see it from different industries that use control rooms that as soon as you automate things, you lose some of that hands-on experience that is important when problems arise - the spinal reflex is not so fast.
>
> ID7: When you talk about autonomy, then you have devices that run autonomously that you perhaps do not follow at all times, and so if they make a mistake or fail, what is the possibility for the person then to correct or deal with that failure. This is where humans come in, and this is where humans are good, when complex things happens. The machines are smart until they are stupid and they fail, and then you should expect people to save the day.
>
> ID8: From an operator's point of view, today you are sitting on board a ship and then you have some such situational awareness in the spinal cord. You may have been out in the ROV garage before it was put down, looked at the ROVs, and saw that e.g. that ROV is old and tired, that arm is like that, and like that, the sonar is like that. Then you go into the control room and see that the weather is like that, the boat is like that, etc. So you have a pretty good understanding of what is going on and replacing that understanding as well as possible I think will be important for it to succeed. For example, when a pilot goes out on a boat to turn on a valve, he is perhaps most concerned that he has an ROV that has the right manipulator arm, is large enough, and what the valve looks like. Everything else has he in his spinal cord, as he is physically

> there in the moment, and this is information that must be replaced - that you have a good understanding of the situation. (A live camera is a good tool for situation awareness).

As ID5 mentions is it important that one does not automate away everything as it takes away the important hands-on experiences and the physical skills refines. Situational awareness (SA) is difficult to transfer to the drones, as well as it is difficult to maintain when only doing monitoring activities in the control room. ID8 also points out a great example of how important it is to have spinal reflex and knowledge about the history of the drone, which is something that humans are great at - to see things in context.

Anderson (2021b) describes SA as: "Developing and maintaining a dynamic awareness of the situation and the risks present in an activity, based on gathering information from multiple sources from the task environment, understanding what the information means and using it to think ahead about what may happen next.". To see the whole picture is difficult for the drones, and is one of the human's best characteristics, but is hard to get when one is not hands-on in the operation. Functions that can assist in getting the necessary understanding of the operation for the human, are the camera function, as well as operational statistics and other visual features. Experiences from previous missions can also be useful as they can provide a greater perspective. E.g. knowing that the seabed has an angle of X degrees will affect A, B, and C. This is something that the drones are not smart enough to realize, as it is a non-technical skill.

It takes time for a person to switch from monitoring to controlling activities and especially when it is required on short notice without sufficient time to gain the full context (Anderson, 2021c). As the human has been out of the loop will its situational awareness not be accurate enough to take full control over the tasks at the moment. To reduce risks associated with the transfer of tasks should the human be highly skilled and trained to manage these types of situations.

The composition of competence in the control room should be carefully composed and evaluated to satisfy the need for optimized HMT. The interview objects have pointed to some important characteristics and qualities that the CROs should have, as seen below, but the competence in the control room will probably change over time as the technology is more and more matured, pilot projects have been completed and one has learned from the experiences so far.

> ID2: I think the most important thing is domain knowledge. That the person must have a very good understanding of what is happening, how to manage a subsea template. You have to be a factory expert, not a robotics expert. Then we have to add up the degree of autonomy and such accordingly. To think that the person in question should just come in and use all these technologies and tools - that is, he must learn the tools. So one should not think that it is so intuitive that one can just sit down and then start using it, training is needed. Factory expert with training in the use of digital tools. A robot is, among other things, a digital tool.

> ID4: There must be both technical and operational competence in the control room... You have to be creative and analytical, and really be able to predict quite a lot about what might happen, and maybe work quite preventively, so try to keep it pretty much on such a strict leash...

> ID5: My experience is at least that once you do an operation, there is a lot of money at stake, there is a lot of responsibility, there are many who look at what

> you do and who depend on the results of what you do, and then it becomes fast a stressful situation and a lot that needs to be done at once to high quality and at a fast pace. Then I think you are not putting a person in the control room who you know does not handle multitasking, stress, or writing and listening at the same time. There are a number of such non-technical things that are important to include when putting people on the console, I think. It is also important to be able to convey this. Be able to communicate clearly and concisely, be able to write down the essence of what is being done, not embroider long essays when you do not have time to write more than two words, and that it is then the two correct words that are noted - short and concise. To be able to communicate verbally, briefly and consistently, to the right people. Be able to make decisions, and know when not to make decisions yourself, but actually need to call the experts. Then some things can be trained and some things that one might assume are in the person's nature.
>
> ID8: It depends a bit on the operation and tasks. It is important that you have good personal qualities, that you do not allow yourself to be stressed, and that if there is stress, it has the ability to remain calm, sort tasks and take the most important things first, and function effectively in stressful and unforeseen situations. I think it is important to understand the limitations and possibilities of the functions that lie within.

As time is an important factor in the control room, as previously seen in the tables for each inspection operation (Table 4.4, Table 4.3, Table 4.2), is it important that the CROs have an understanding of how time affects the criticality of the operation and can make prioritized decisions based on this. As Bainbridge (1983) says: "Humans working without time-pressure can be impressive problem solvers. The difficulty remains that they are less effective when under time pressure.". As the interview objects have mentioned are human factors such as problem-solving, multitasking, communication, and stress management important to have in the control room, and factors that help to complement the needs together with the machines. The type of domain competence each link in the control room needs is also suggested in the tables as it differs for each operation or organizational structure.

The attention-getting principle presented is also something that must be included in the systems, especially in the alarm and error reporting system. This to catch the CRO's attention as multiple things are going on at the same time.

Human and Machine

To be able to succeed with this control room is the optimization of human-machine-teaming (HMT) a key factor that we are dependent upon. Autonomy on the drones is a great function that humans have authority over. However, the interactions between the CROs and the drones will need collaboration, especially on the stage that the autonomy is at today. There are a number of factors that must be in place for the system to operate fully autonomously, including trust and risk.

When it yields for control of the drone is this a function that (at this stage) includes human interaction. There is not enough trust in the system at this stage, and it will be necessary for the CROs and drones to communicate step-vise during the mission or for the CRO to manually control it with a joystick or similar. Communication during control can be easy yes/no-commands given from the CRO(s) for stop/continue messages sent by the drone(s), or the drone(s) telling that it cannot do the task and CRO(s) must take over.

> ID3: The machines must try to give a warning that now the human must enter the loop because now I will do something critical here that I can not do myself properly.
>
> ID4: We depend on human-machine interaction. If you envision this as a house of cards, it is quite clear that if in a way the decision-making systems and autonomy systems onboard the vessel does not do what they were designed for, and they do not manage to incorporate people in a good way in decision-making support and the decision-making process, then there is no way around it.
>
> ID10: If you are going to turn on a switch, it will probably go well, but if you are going to consider something while you are working, I have dug well enough so far and think it is more difficult. In order to reach that [autonomy stage], one must develop the autonomy software on the drone itself. Where we fumble a bit is what we need to do to be able to describe the mission plan of that drone and how can we validate that the mission plan is complete before we actually do anything. Being able to validate a mission plan, either through a simulator or with formal methods, is enough to both engage externally and to spend some time even on how we should/can validate a mission plan, and be sure of that he [the drone] is going to do that job.

As ID10 mentions are there several aspects around the autonomy that is not in place at this time. Either way is the interaction between humans and machines essential for this to work.

4.2.3 Step 4: Define task requirements

This step is not considered and evaluated in this thesis, as it falls outside the problem statement.

4.2.4 Step 5: Design job and work organization

Research question 3 (RQ3) focuses on how the various parties involved in this control room should *samhandle*(cooperate). As seen earlier are there several groups or divisions that must be included in the control room in some way and they all need to cooperate. This step, therefore, presents suggestions to the design of the organization structure, as well as data streams and communication that needs to be in place to facilitate and fulfill the needs of each party involved in these complex operations. This fifth step in this design phase focuses a lot on tasks and how they are assigned to particular roles, but as we are in a very early phase of the design is it too early to allocate jobs and requirements for each operator. However, this step does tell something about which stakeholders and key players are needed for this to succeed and which roles they play in the ecosystem.

There are several ways to organize a control room for this fleet of UIDs. As seen in Table 4.4,Table 4.3 and Table 4.2 are there different professions involved in the operations before, during, and after, having different responsibility for the operation(s). Having many different stakeholders, companies and parties can present some challenges, and communication and cooperation between them all must be in place.

A list of necessary key players for this UID control room is presented in Table 4.6. These form the basis of the ecosystem in place and should all be connected to the UID-control room in some way. When designing and developing this control room should all of these key players be integrated at some time in the process, especially since they also present the multi-disciplinary team that is so important in HFE. As seen in the table have each player specialized competence within a field and each plays an important factor in the total picture. Notice that not all players have a direct link to the control room, but is important for the ecosystem that the control room is monitoring/controlling. This list is based on feedback from the interview objects and gives the necessary multidisciplinary perspective that is needed in HFE.

Table 4.6: List of key players in the ecosystem with examples of relevant companies

Key players	Description/role	Examples of companies
Operator	Field owner and its internal divisions. Has the overall responsibility of the field and orders/delegates task out to contractors.	Equinor, Exxon, Aker ...
Platform Supplier	Delivers the sensor platforms (UIDs and docking station). The hardware part.	Sapiem, Eelume, Kongsberg...
Sub-supplier	Software suppliers for the sensor platforms. Delivers (IT) systems for autonomy and automation, as well as planning-software	SkarvTech, Kongsberg...
IT-systems	Delivers IT-systems for communication, analysis, etc.	Microsoft, ...
Communication	Deliver fiber optic infrastructure, communication, etc.	Telenor, Tampnett ...
Underwater communication	Delivers systems for underwater communication	Evalogik, Teladine technologies, ...
Subsea equipment	Delivers subsea equipment, such as pipelines and templates.	Aker Solutions, TechnipFMC ...
Data analyzers	Companies that are specialised in data analysis, which are domain experts on the collected data. This can be environmental analysis/monitoring and condition monitoring	OmniSci, NGI, ...
Others	External clients, customers, contractors	

> ID4: One should have put together a development group to work with this: who should it consist of? I think in a way that this is a rather multidisciplinary competence issue. ...I believe that from the very beginning you have to work with those who deliver the systems, those who build the algorithms, those who build the communication platform. All of this must in a way be part of a kind of iterative coherent process. It is clearly challenging to do that, but I think you are in danger of failing if you do not do it. You can look at places where they have made it, such as NASA, which is one organization, and that organization

> has all these subgroups, it owns in a way all this expertise even then, the field operators do not that, so they have to bring it in remotely then.
>
> ID5: The first is perhaps to set up a list of users, or user involvement at an early stage is very important, so we know at least what it is each one needs.

When it comes to the organizational structure are there, as mentioned earlier, different ways to design the room (structurally)[3]. The structure and concept are dependent on the key players as well as the support functions necessary for the control room and its ecosystem.

An important factor to evaluate when designing the control room concept is the operators' workload. HFE focuses on optimizing humans and machines, and meaningful human work is best obtained when human tasks and performances are optimized. As ID7 says: *"It is like we talked about, with people in perspective, workload, staffing, and concept for the control room. Whether you should have a control room or what type of solution you should have, must you scale it according to the needs."*. Exact work tasks in the control room for the CROs are difficult to clarify so early in the design phase, as it also depends on the concept/structure of the room. The same yields for team structures. However, it is clear that the communication line and lines of authority and responsibility must be established early on, with the field operator in overall charge, and that the pilots of the fleet have the necessary licensing that is needed for controlling underwater drones. When the concept of the control room and its ecosystem is decided, must jobs carried out by each CRO be defined and delegated in a way that optimizes the workload and HMT, and in a way that maintains good communication and interaction.

Which tasks should be delegated between the key players is also something that the field operator has to evaluate and decide, and is also something that needs to be considered in each of the two models. Shall the UID-control room monitor subsea equipment placed at the site of interest, i.e. take over some of the process plant's tasks, or is it just monitoring the sensor platforms, as ID6 point to:

> ID6: It is a bit of the same discussion we have when we talk about condition monitoring of a complicated compressor or a generator on a plant. We then have a choice of whether we should do it here in our own room with our own people, or if we will put it out here to the person who delivered the compressor and let them monitor themselves on our behalf. We do it a little differently, it goes like a pendulum, it can swing so that one day the management decides that we should do it that way, and then the pendulum swings and says that we can just as well do this ourselves. This could probably be the same challenge here.

It is a question of responsibility, but also workload for the CROs and composition of the team inside the control room.

One of the dilemmas in this problem case is proprietary control rooms. There exist several drone suppliers that deliver different types of UIDs with their own (IT) systems. They again have their own sub-suppliers providing different functions to the drone, e.g. the software, and then we are left with many different systems that the operator company has to integrate into their systems again, as there is a lack of standardization in this area. On the other side is the field operator that has the overall responsibility, making sure that everything works well by delegating out tasks and jobs, and makes sure that the ecosystem is fully functioning.

[3]This thesis does not focus on the internal physical design of the control room, but looks at the organizational design based on the function analysis.

> ID6: Connecting all actors is perhaps one of the most difficult tasks here. It is often easy when there is a huge, well-known, and established supplier who becomes the driving force and either sets that standard, or perhaps in most cases may not set a standard, but a proprietary standard that often does not provide a good overview which drives things. Here it is perhaps a little bit different, that there are many small companies, and then I do not know if they lack the integration partner, the one who will actually have ownership and integration here (the integrator), and that is perhaps the most difficult here.

Combining each partner in the ecosystem might become one of the most difficult tasks when designing this UID-control room, as ID6 mentions, as well as the many proprietary solutions which can present some integration problems and lack of interoperability.

Based on the input from the interviewees is the following two models actual. The two models/concepts differ in who controls the UIDs, as they can be supplier-controlled or operator-controlled. Data streams are also outlined in the models, as they are important for communication in the ecosystem. It is as mentioned earlier assumed that the docking station is universal and can be used regardless of the type of drones. Both models are designed hierarchically, with the field operator at the top.

> ID5: I think in the control room situation it is important to have both a hierarchy of responsibilities in the control room, but also systems that allow such an overview

> ID7: A dilemma is that if you have several different suppliers who also have a role here, what do they do? Do they control the drones? One must map responsibilities and roles between what the suppliers have, if they have a role in it, and what the control room has. If you have a virtual control room where people sit in different places, can you imagine something like that, that you sit in different places and control it here?

The models take into account the dilemma mentioned by ID7, and the temporal constructs from Table 4.4, Table 4.3 and Table 4.2.

Alternative 1

Alternative 1 presents a control room where the field operator does both jobs: control *and* observe/monitor the drones. The field operator will in this model have full control over the fleet of drones and its operations, as it owns the drones and has its own personnel performing the tasks in the control room. The CROs have the necessary technical competence for managing the drones and their operations, and other support personnel is close nearby/within close reach. The fleet of drones can consist of a diversity of drones that can connect to the docking station and transfers the data to the control room, regardless of the drone supplier. The model answers the need for only having one control room and that the control room is less drone supplier-specific, as ID6 points to, and cut out the need for a second joint in the communication line, as the control room and the sensor platforms have direct communication links. All data to and from the sensor platforms are transferred through the control room, and there is no need to split it on the way.

> ID6: We want it to be less supplier-controlled - it can not be the way that each individual drone supplier should control this, it must be something that comes

> from the outside. I think to an even greater extent than for a number of other systems, must the operator (the owner of the plant) set much more premises to avoid having too many supplier-specific things.

This model is hierarchical, meaning that the control room and its operators are on top of the system, getting all necessary information and data streams. As seen in Figure 4.4, does the control room get its data directly from the dock and drones, and the control room works as a central hub for the collected data. Further distribution can be done from the control room to other departments or external personnel, as also seen in the figure.

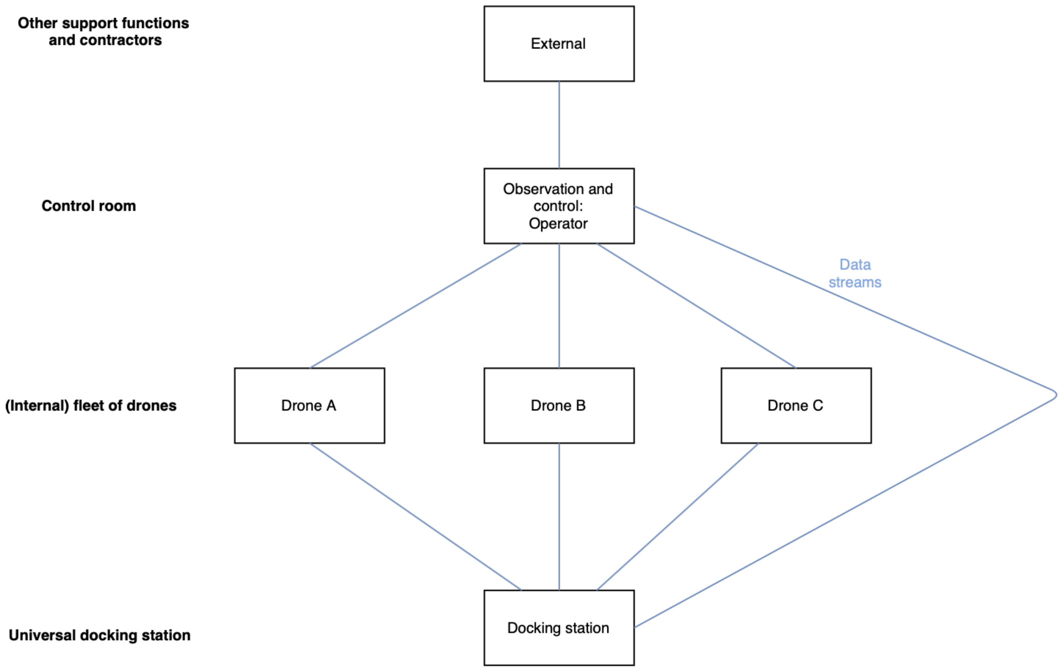

Figure 4.4: Visual representation of alternative 1. Here has the field operator both roles in the control room: control and observation. The room is independent on the drone supplier and type of drones.

The competence in this room must most likely be both technical (different engineering fields) and analytical, as the operators control all parts of the operation. As the drones are controlled by the operator company will they most likely not have (enough) robotic competence if a technical error occurs on the drone(s) - which is also something that should not happen often, and therefore not be necessary to place in the control room. It is also a point that the fleet will consist of different drones from different suppliers, which then means that there is a need for one robotic expert for each drone supplier. This will not be effective, and the solution to this is to just have a communication link and call the company if something happens. However, should one consider what ID6 proposes with condition monitoring:

> ID6: If it is the operator who drives them himself, then there should probably be some agreements or something like that, and maybe then on the technical side, which means that someone is sitting in the backroom of those who own the drone(s), but who not only supports the operator, but who actually get some data from all the drones they have at different field operators so that they can

> actually follow and do a condition monitoring on the drones at the rear, but without them being an active part of the operation. I see this as a potential and it is something we are working on other types of equipment that is also immature insofar as we get suppliers into the loop to do what they are good at.

How this should be implemented and carried out is not further investigated in this thesis.

This model can be related to an *industrial platform*, a digital platform that is built to transform traditional manufacturing into internet-connected processes that lower the cost of production and transforms goods into services. It is functioning as the basic core framework for linking together sensors and actuators, factories and suppliers, producers and consumers, software and hardware, (Srnicek, 2017). The platform has a relation to Industry 4.0 [4], which is the fourth industrial revolution, better described as an evolution where existing technology are connected in new ways to further contribute to efficiency and cost reduction (pwc, 2021). Using technologies and frameworks from Industry 4.0, such as OPC UA [5] and RAMI 4.0 [6], can make this concept solid. This should be further investigated.

The model is the simplest of the two presented when it yields for communication lines. The "in-house" control room has its pros and cons and is perhaps not the best solution to start with when it comes to these types of operations, as the technology is not fully mature and developed. However, this concept can make it more orderly within the organization, as already existing systems can be linked and used in the control room. Apart from that, is might the biggest challenge how to supplement the fleet with new drones from existing and new companies, as they might be developed in a way that is not supported by the already existing system(s).

Alternative 2

In alternative 2 are the roles of control and observation split. In this case, does not the operators manage the fleet of drones, just order task and missions to the suppliers - they are planning the operations and observes it. The suppliers control the fleet that exists of drones that they provide (or collaborate with). The suppliers report to the field operator company. This is a more proprietary solution and is presented in Figure 4.5.

> ID5:I would probably have organized it in such a way that if this fleet of drones has different suppliers who must have an overview of their own drone, then I would probably put an extra person on top there who had more as overall responsibility for it all. So that each supplier, who sits with his drone or vessel, must report to the superior responsible with the essence of what is going on, not necessarily details. There is a person at the top who pulls in all the threads and has an overview picture. So this has to do both with the technical aids in the control room, but also the organization in the control room, and it is important that the line there is clear and distinct - that the responsibilities are clarified, reporting, that everyone knows who does what, who has responsibility for, what who has authority for what, etc.

The fleet of drones that are controlled from the control room is, as mentioned, performing three different inspection operations. As the control rooms are proprietary and the drones are differ-

[4] The term is derived from the German word Industrie 4.0
[5] UPC UA: open platform communication unified architecture
[6] RAMI 4.0: Reference Architectural Model Industry 4.0

ently equipped and programmed, can different suppliers perform different operations on behalf of the overall control room. Having proprietary control rooms also makes it possible for the drone suppliers to connect to other field operators' observation rooms, as seen in Figure 4.5.

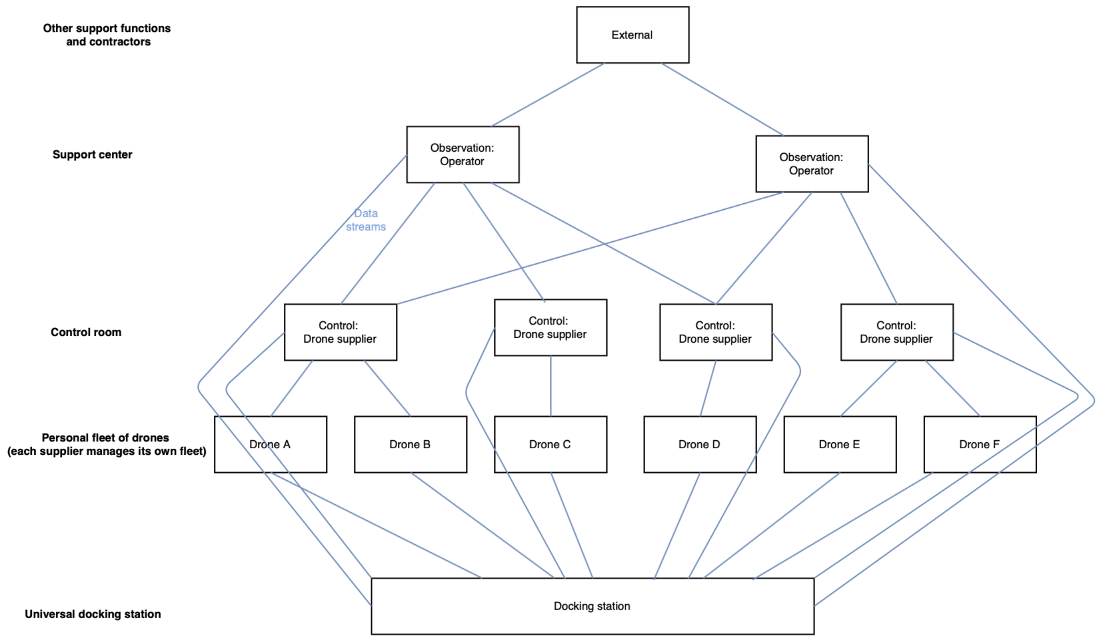

Figure 4.5: Visual representation of alternative 2. Here does the field operator only observe and the control is managed by the drone supplier itself. Having proprietary control rooms make it possible for the drone suppliers to connect to other field operators observation rooms.

The data streams in this system are a bit more complicated as seen in the figure, as there is splitting in which type of data each room gets.

> ID1: As we have set it up, the information goes from the drone which is split up so that something goes straight to the contractor (those who have made the drone and are controlling it), and then some information goes to the center that comes with.

> ID6: Then we will have the data that we may have bought and paid for, either directly to us or via the supplier, but then maybe the supplier will have opportunities to monitor his thing which is the drone, which often needs to be updated with some software, or that it will get operational data from the drone itself which we have zero interest in us as a company, but which is of interest to the person who owns or operates/controls drones, and perhaps the information there that is logged, but which one has not been able to record in real-time. That must be manageable through such an infrastructure. So then you get the drone and the drone supplier, and then you get operator infrastructure in between, and then one would like to have it up to the drone supplier up at the other end. So there are quite a few both the channel and aspects here with the data that in one way or another should be taken care of.

The control room that controls the drones only needs the (critical) real-time data to run the operations. This is some of the data that the sensor platforms produce. The observation room, however, is more dependent on the non-critical data. However, e.g. in check and report missions is the collaboration between the two rooms crucial and then they both might need the same data. How to solve this, is first of all dependent on the chosen business model, and secondly how the communication technology develops and autonomy. An important question to ask is if all actors should have access to all data transferred from the dock and drone, for security reasons. This should be further discussed if this type of model is relevant.

As alternative 1 is more like an industrial platform can this alternative be seen as a combination of *the product platform and lean platform*. Which of the two will be dependent on the chosen business model, but with the greatest emphasis on the first one. Product platforms are generating revenue by using other platforms to transform traditional goods into services and by collecting rent or subscription fee on them - goes from selling a low margin product with less revenue to sell a service. The lean platform attempt to reduce ownership of assets to a minimum and to profit by reducing costs as much as possible. It is a virtual platform that owns the most important assets: the platform of data and analytics. (Srnicek, 2017).

A control room with this type of structure will require a system where tasks/jobs are announced by the field operator(s) that the different fleets can sign up for. There are multiple ways to delegate these jobs, but an interesting thought is to have a system that is similar to how Uber, a lean platform, works. Having high-level mission planning, where jobs are announced and it is first-come, first-served for the different companies with fleets in the area. However, will this "Uber situation" not be fully operable, as ordinary people will not own UIDs and be a part of the "society", getting profit for taking on inspection jobs. This sharing economy philosophy is something one can be inspired by.

What is possible for the suppliers to do, is to have a business model where they instead of selling their drones to the field operator, as they do in alternative 1, sell their product as a service where they guarantee up-time, as mentioned by ID2 and "Maybe will the operator buy the control room as a service from a supplier" (ID2):

> ID2: ...when the degree of autonomy of a system increases, what exactly is the service provider's role in it then? If you have a drone that can only fly out and do what is needed even without you needing an ROV expert there, does one really have any need for service providers then, will there be service providers in the future or will there be companies that sell technology as a service? Today we have an ROV provider, we have an ROV service provider and we have an end-user. If an ROV supplier now only sells that ROV as a service, that the ROV supplier says "hey, here you have an ROV and just press the green button and it will do everything it should and we guarantee the uptime". This is just such a typical example where a Rolls-Royce aircraft engine sells "used aircraft engine hours", they do not sell the aircraft engine itself, they just mount it on the aircraft and then they sell used aircraft engine hours. So they have an uptime.

Which business models the different players should go for and how to delegate the inspection operation-tasks, is not further researched in this thesis, but is interesting for further work.

Table 4.7: Summary of the two alternative concepts for the UID-control room's organisational structure, showing their similarities and differences

Point of comparison	**Alternative 1**	**Alternative 2**
Fleet/drone owner	Field operator	Drone-suppliers, field owner rents
Type/number of rooms	One control room (in-house)	Proprietary rooms (drone-supplier) + observation room (field operator)
Controlling the drones/fleet	Field owner/operator	Drone-supplier
Observing the drones	Field owner/operator	Field owner/operator
Digital platform	Industrial platform	Product platform, with some lean platform philosophies
Delegating jobs/missions	In-house	Outsources to drone-suppliers
Implementation	Might the best solution in the long run, but difficult to gain at this point	The best solution at the moment, but might be phased out with technology improvements and development

Other inputs

Another interesting thought on business models, mentioned by ID9, is to have the subsea-equipment-providers deliver their equipment together with drones for inspection tasks. By this will the companies be forced to include the drone element when planning the field instead of putting it on afterward. This can for example be done by providing an X year-long contract with company A that delivers Y number of drones. This package solution will probably favorite one company of drone suppliers, which might not is the best one. Another aspect to have in mind for this solution is technology development. At this stage is the technology still undeveloped and it is not sure that this solution will be the most sustainable. To fit into alternative 1 must the field owner buy and implement the type of drones into its own systems, and it, therefore, is an input that fits alternative 2 best, where the drones are controlled proprietary.

A question that also must be answered is where the room(s) should be located. Some support functions might not need to be located at the same place as the control room operators, as there exist digital communication technologies that provide almost the same characteristics as being physically in the room, and the solution/system can be online.

4.2.5 Step 6: Verify and validate the obtained results

Not actual at this point.

4.3 Development plan

It is difficult to present a development plan for a UID-control room in a field that is so multidisciplinary and is depending so much on technology development and maturity. Several factors affect this plan, including the business plans for the companies involved and their willingness to cooperate on the development of the design. As this thesis focuses on designing and developing a control room for fleet management of drones in general, and not for a specific company, has it shown that the intention of this development plan as a staircase model, is not presentable, as there are too many factors to evaluate and analyze, as well as investigate. Also not having the full overview of where we are today and the progression on autonomy for each supplier company and their strategic approach makes it hard to present the development as planned (this could probably be an interesting study for further work). Instead, are a list of the most central elements that will influence the development of the concept, and those are dynamic factors affecting the development, presented in this section.

What can be said, is that the development of the UID-control room will not be easy and that the field operator organizing the control room must make a strategy and plan for how this design can be executed. In their plan, they should decide which type of concept they want and how to include all the other suppliers and contractors, as well as getting the best people/competence to get this up and running. This will be expensive and the question is whether the operator thinks that it is worth it and sees how much potential and value it can create.

The first factor is the autonomy of the drones. This is as mentioned a couple of times earlier, a function that the control room is dependent upon, and that will be very important for fleet management. Finding the right LoA for each situation and optimize HMT is crucial, and just the point of removing the umbilical connecting the drone to the control room on site is a challenge, especially for ROVs. Being able to control them remotely from shore is the first step. This can be done using the docking station instead of the vessel, which also removes the forces (waves, drag, etc.) affecting the cable when the drone is lowered from the boat. The next step from here is to let the drones perform missions and tasks without the cable using different degrees of autonomy.

Managing X number of drones will not be possible without some degree of autonomy on the drones. Software for autonomy is, therefore, a key element in the development of this project, and important momentum here are safety, trust, and communication, as well as keeping the human in the loop. Improving underwater communication and bandwidth will also be important for the control room and the drones, as it can make it possible to get the necessary real-time data making the operations safe and effective.

When it comes to other technologies that can be put in the control room or that the room is dependent upon is it important that they are seamlessly put together and that there exists interoperability. Many of the systems and technologies that the control room needs already exists today in other industries, but in different contexts, so it is about putting them together in a way that gives the HCD approach, as well as every other important functionality. It must be flexible, scalable, and robust.

Technology optimism will probably affect the project, and there is a risk that this can may cause ignoring of human factors. Another factor is to predict future users, which can be hard, considering that the needs will change according to technology development.

Step 5 in phase B (section 4.2) presents two types of models or concepts that can be used for designing this control room. Where we are today versus where we are in 10 years will not be the same, and regardless of which concept one wishes to go for, is it most important that it can be changed, improved, and be further developed along the way, as one learns what works the best. How the organizational structure of the control room develops will most likely be affected by the improvement and development of the technology and autonomy. When it yields for the competence placed in the control room will the needs here also change with time and technological improvements. We might start with having experts on robotics and the specific drones available, but with time, will we most likely move away from this, and use other problem solvers or pilots in the control room. The field operator must decide how much responsibility it will have and how much of the work it will do itself - the rest must be outsourced/contracted to other reliable and innovative actors.

Looking at the inspection work processes, will one probably start with one of the three, and expand further as time and technology goes. The easiest operation to implement will probably be fixed monitoring, as this is an operation that does not involve close contact/interaction with the subsea equipment, and will therefore be ranked as the safest operation at the moment. It is also a type of operation that does not have the same need for real-time data as the other two. When it comes to planned inspection missions, will they not be far behind when it comes to visual inspection. Since check and report missions are based on real-time data will this probably be the last type of work process implemented. This because the underwater communication technology is not quite where it needs to be for this yet.

Chapter 5

Discussion

This chapter discusses the main findings of the study presented in Results and Analysis. The discussion is primarily centered around the positive and negative sides of the findings, but it also evaluates it up against the background basis with its theories and methods from chapter 2, especially with a focus on the function allocation dilemma and in light of the capability stack model.

The chapter does not discuss the problem statement and/or each of the research questions (RQs) directly, as it also was not the case in the previous chapter. Instead are the main findings from the interviews, where the RQs and the given case were discussed directly or indirectly, highlighted and evaluated here.

5.1 Capability stack modeling of the UID-control room

The capability stack model (Figure 2.3) presented in chapter 2 was used as a basis for this thesis, and we see that the control room and the results in this study cover different parts of the model in their own area and way. The model covers most of the ecosystem needed in this UID-fleet management case, but some parts differ from the model, as they are dependent on structural approach and business models. However, are all the five niches in the stack touched upon, but with varying degrees, as the problem statement does not cover all parts of the model directly.

At the next lowest level of the stack, we find the sensor platforms that need an intelligent infrastructure which is in most cases is dependent on the technology resource layer (the lowest level), as it is hardwired together. These two layers were the main focus in the student's specialization project and are not in special focus here. However, we see that there is a need for standardization at this level so that equipment and sensors can easily be adapted to the sensor platforms, as well as integrating the sensor platforms to the control room. It is also a need for further development on autonomy and to mature this technology, to gain trust in the sensor platforms, making it possible to perform the three inspection operations using fleet management. A study should be made in connection with the selection of the type of drones and equipment.

"Information and work processes" is the central hub when it comes to the data flow. This joint is crucial for collaboration with other support functions and information flow, and we can place a lot of the functions and systems presented earlier. However, in the model is the data split and transferred to each function/room, which is a bit different from what is presented in this thesis, where everything goes by the control room(s) and is from there distributed out to external/other divisions. This has to do with temporal rhythms and coordination, as well as organization. Making a system that can handle the data and filter it out to the necessary users will have a huge potential, but will be difficult to develop at this time and must be further investigated. This part of the model touches on two of the layers, information, and collaboration, and knowledge-sharing and analytics. These levels include several factors that the functions presented will take care of, such as analysis, sensemaking, visual interaction, and awareness. This is achievable by processing and managing the data and information streams for the control room's best.

At the top of the stack and model, we find among others the control room. This is the business operation layer and is where the operations are executed and controlled. Planning is a part of this, and the mission planning system uttered is important for enabling this. Together with the data streams, in real-time or from docking, can decisions be made according to IO's vision: making faster and better decisions. Looking back at the seven drivers and success criteria in IO (Figure 2.2), along with the four influencing factors in Table 2.2, we see that we are creating value with this UID-control room by integrating each and every factor.

The stack model provides a great overview of the factors affecting the control room and its development, and the layers express the most important characteristics and responsibilities that must be in place for each. The results show us that each part is important, but that they have different temporal conditions that the system must adapt for and that affects each part of the stack in some way.

5.2 Potentials and Downsides

This type of control room presents new opportunities and solutions not only for the O&G industry but for other industries as well. It makes it possible to show new things as well as taking advantage of the things we already have in a new and innovative way, and put them into a new context. As mentioned in existing work in chapter 1, does a lot of the systems needed in the UID-control room already exist today, but are not integrated for this specific purpose.

Much of the design of the control room depends on the companies business models and strategies, as well as how much resources they are willing to contribute. This is not elements that have been considered here as it falls outside the problem statement, but also the field of competence of the student. However, it would be interesting to see what this type of control room cost in regards to resources in a socio-economic context. Regardless, many potentials and great opportunities are depending on the motivation of each actor involved in the room.

Placing a stationed fleet of drones at the seabed performing the three inspection rounds gives some advantages. Having a fleet continuously monitoring and observing a field/area, can reduce costs and save the environment for damages caused by faults in the equipment. The fleet contributes with a lot of data that makes it possible to easier detect faults, and it can then be repaired before it expands and gets much more dangerous and costly to fix.

One of the major downsides with this control room at this time is the lack of maturity in the systems. Undevelopment, primarily on autonomy, presents challenges and perhaps provides the project with a sense of utopia. However, according to the interview objects, is the project manageable and feasible, but it will take time. It is also difficult to plan and design for the needs of the future, as they will probably change in line with the development of technology.

5.2.1 The two presented models/concepts

The two models/concepts presented in chapter 4 and visualized in Figure 4.4 and Figure 4.5 has their advantages and disadvantages, and is not necessarily the best solution(s) to the design (in the long run). It is difficult to see which concepts that the field operator and/or owner chooses, as for which one to recommend. It is very dependent on the business model(s) and how much control and responsibility the owner wants in the development phase and further development. It will also depend on what platform strategy the company wants, as some companies will want to build themselves upwards in the stack model and deliver new services based on the lower layers of the stack, where they provide services today.

The perks of going for a concept similar to alternative 1 is that the field operator will have full control of the operations and it is clear who is in charge. Having both the observation room and control room merged in some way, solves much of the co-location problem and gives the operator/supervisor the whole gaze of the operations and situations. Placing the control room with only fleet management in a center with other control rooms managing the facility remotely can provide great potentials.

As I see it, is option 2 the most logical choice of concept right now, because it allows the operator to learn along the way while the technology on underwater drones evolves and develops. Many things need to be organized and this is perhaps the best solution at the moment, but only temporary. In the long run, should not alternative 1 be ruled out as the solution one should approach - that the operator itself takes control of the drones and operates everything within its organization. Whether this is a profitable solution for the field operator is difficult to say anything about right now, and one must look at the market and the development of drone technology, as well as the motivation to know for sure.

Regardless of the model, it is important that the chosen model preserves the human factors, and does not let them go at the expense of technology and other means/assets. The type of concept should also be decided early in the design phase.

5.2.2 Competence and temporal conditions

As seen in the operation tables, have the groups connected to the control room different temporal rhythms and conditions, as well as background. Each function has its own set of tools for interpretation of the data and its own mathematics, meaning that it cannot be reduced to common perception. This can yield some challenges when looking at and placing the data in a larger context.

When it comes to the co-location of the control room and its support functions, is it dependent on the organizational structure that the field operator chooses, as well as the needs for each function, which in most cases will be dynamic. However, the control room(s) should be located at one location with its personnel. It will also be an advantage to have some of the most important support functions nearby, as physical communication is better than digital communication in some cases, as one can use body language and point out interesting and/or important moments during the operation. When it comes to competence and support that acts upon long temporal rhythms, can they be placed regardless of the control room(s) location.

As seen in the operation tables are there many professions and fields of competence that have use of the data accumulated by the drone fleet. This for making predictions, monitoring the area, detect abnormalities, research, and other types of analysis. The shows that the value creation of this control room is high and that it involves a lot of people with a diversity of competence. When it yields for the control room, we see that the competence of the personnel placed in the room is dependent on the room's structure/concept and technology. Some necessary characteristics for the human operator were presented earlier, but exactly what knowledge, background, and experience the staff should have will be up to the development and owner. It is possible that in the long run, we will have engineers, or equivalent, with subsea competence who control the operations after undergoing additional training/capacity building for drone control-making fabric experts.

5.3 Technology optimism and Autonomy

The UID-control room might be excessively affected by technology optimism. This meaning that the people behind/included in the design and other relevant parts are overzealous about what is possible to achieve, as their look at technology development is a good one, and they are positively to use technological means to solve societal problems. However, this might go at the expense of human possibilities and limitations.

Evaluating technology optimism in the case of this control room might be needed, as the room is affected by several factors that influence the technology and its development. Some of the most influential forces are mentioned below. Key factors for making the control room succeed are to give it significant flexibility and scalability, using enabling technology while keeping the human in the loop.

5.3.1 Allocation of functions

Each of the functions or systems presented in chapter 4 will be important in the control room or by its support centers/external groups. How the systems and functions should be sewed together, is not something that can be answered at this point. It is as mentioned, dependent on many factors, including the type of structure, existing systems, and databases for the actual companies involved.

The human-machine system must be adapted to handle unexpected circumstances, and the functions must be allocated accordingly. What this study has shown us, is that ISO 11064 does not consider autonomy and the dynamic allocation that happens as a consequence of this functionality. This is seen as a weakness with the standard and is further evaluated in section 5.4. A priori allocation of function does not work in this case, as we see that each use case has its own needs and different LoA.

ISO 11064-1 states that functions must be distributed between human and machine and that one alternative to the traditional fixed allocation (static allocation) is to allocate the functions dynamically (adaptive allocation). By dynamic allocation, they mean that the system interface can enable certain functions to be allocated according to the prevailing workload, and the human can take over machine functions in the case of faults. The ISO also notes that it can be necessary to provide additional information or support systems for the operator for making it possible to perform the machines' role if necessary.

Even though the ISO barely mentions dynamic allocation, does it primarily focus on allocating the functions based on performance characteristics and cognitive support - it has a static allocation approach. The HABA-MABA-list presented by Fitts (Table 2.6) tell us something about who is good at what, and as the functions listed are primarily technical, is important to let the machines do what they do with processing and visualization of the data, and present it in a way that supports the human users/operators to the fullest, and vise versa. It is just expected to list up who is responsible for each task, and if necessary, iterate through them for further distribution. And as we have seen in this study, is this not possible in this case, as the use-cases have different needs for functions and human-machine control and collaboration.

It is also mentioned that additional information should be necessary to provide to the operator if it must take over the machine's task due to faults when dynamically allocating the functions. However, does the ISO not state anything about how this can be handled or avoided at best in the design of the control room. In this control room will situational awareness be an important factor to facilitate, as the drones are operating remotely. This is something the standard could have highlighted, and it could have proposed several steps for making this possible while taking care of human factors.

Human factors focus on clarifying and describing tasks and sub-tasks early in the design phase, and it is the first phase of the design process (Phase A). In dynamic allocation is it assumed that the allocation of these functions can be defined beforehand, but looking at this process in this study, we see that it is not possible here, as the functions require autonomy and interaction in a different way than what the methods dictate. The idea that one can anticipate all potential functions from the start is illusory to believe, as the system needs flexibility. It must be possible to change modes along the way and adapt to new and unforeseen developments as needed. This has proven to be an important design problem.

In the discussion of allocation is it mentioned that there are too high costs in making prototypes and re-allocate functions as a consequence of the feedback from users in the testing phase and that the functions, therefore, have to be allocated before the system is designed. Performing a functional analysis shows us that it can give some answers to how to design the system, but it also shows that when designing a system that is dependent on different degrees of autonomy, is dynamic allocation important, but it does not cover or include all the necessary aspects. This type of control room will need testing and piloting before it becomes fully operational, which contradicts the process of function allocation.

In this control room is it necessary to allocate and re-allocate functions dependent on the use-case and its tasks. Static allocation does not allow for re-allocation of the functions more than once, and a dynamic approach must therefore be used. However, will a system that is based on dynamic/adaptive allocation be capable of re-allocating functions, tasks, and responsibilities between human and machine, based on a pre-selected real-time criterion. This is not completely optimal in this case, as the use-cases can provide challenges that cannot be foreseen and hence predefined.

In dynamic allocation is the allocation continuous and the LoA can change frequently to impact the human workload or for executing work that the machine is better at than the human operator. A list of who does or should do what, must be developed and a strategy that substantiates this (re-)allocation for each use-case.

Autonomy on the Drones

The biggest challenge of designing this control room is the development of autonomy on the drones, and it is a function that demands flexibility in each use-case and dynamic allocation. At this stage are not the drones capable of performing (all) tasks that are wanted without help from a human operator sitting in a top-site vessel, and there must be a stepwise lift in the technology at this stage, as mentioned in section 4.3, for the UID-control room to be operable. As a function is autonomy crucial, but having different degrees of LoA in each operation and its following tasks, makes it a dynamic situation that will vary from situation to situation, depending mainly on the task itself, the surroundings, and the given trust. The autonomy of the drones needs to achieve maturity and trust, along with optimized HMT and robustness. An important element when designing the autonomy system(s) is to ensure that the human factors are taken into account, making it easy for the CROs to control many drones at once. This is where the results from the system/function analysis come in, helping the machines and humans performing together with autonomy.

Either way is autonomy on the technical side the biggest challenge to achieving success with the UID-control room. This because you can say that other functions that a system should have are not strictly limited to the technical challenges, it is more the sewing together part that is difficult here, and to make the autonomy seem/operate robustly.

5.3.2 Maturity, Trust and Robustness in the Technology

One key challenge with this control room is maturity in the technology or lack of maturity in this case. At this stage is there not enough trust in the systems for the drones to operate on their own. Maturity and trust in the systems overlap a lot, as maturity leads to trust, and trust cannot be established without maturity, and robustness must be maintained.

Maturity in the systems is achieved over time with research, testing, and piloting. For the control room, is it the drones that are mostly undeveloped, but the systems in its whole must also mature. When it yields for the control room will one probably start with proprietary control rooms where each supplier controls its own fleet (alternative 2), as this will mature faster than what we see in alternative 1. That the technology is immature and undeveloped makes the project a high risk, as one must be willing to spend a lot of resources and time to develop it. This yields for all parts of the projects, including its key players.

Digital maturity also yields for the organizations, not only the hardware and software technology. As seen, is it a digital transformation going on in the O&G sector today, and digital maturity is a part of this transformation. The organizations involved in the design of the control room should therefore be adaptable for digital transformation and optimize human-machine teaming, keeping the end-users in focus.

Trust in the system(s) refers to that the data input and output are correct and dependable - that the data have a high quality and are reliable. This is crucial in the control room, as the readings must be right for the CROs to obtain a safe state in the field. It is also important that the data the control room gets are correct and does not have (huge) deviations, due to assumptions, approaches, and rounding error.

It is mentioned before, but making a robust system or systems is crucial for this control room to function. A diversity and number of systems and functions are supposed to be integrated and work together, which is not an easy task in itself. The system, both machines and humans, must withstand the strains/burdens and stress it is exposed to, and the vulnerability must be small for this to work.

The technologies must be puzzled together seamlessly *and* have high robustness. This can be achieved through good analysis on the systems vulnerability and risk assessments, which should include specification on consequences and expression of how likely these are. There cannot exist high probabilities for error for the system when it is supposed to work in a dangerous area, as this can cause a major crisis for humans, organizations, and the environment. For IT systems, does also robustness include the ability to cope with errors during execution, as well as deal with erroneous input(s).

5.3.3 Standardization

One of the major problems when it comes to technology, and specific drones and robotizing, is that there is a lack of standards in the area. As a result of the few standards must designers reinvent the wheel over and over again for each project, as some of the interview objects have expressed. Introducing standards is also a way to avoid monopoly situations and open up to new actors in the field.

Standardization is an important concept for this UID-control room, both on the physical infrastructure with power, network, and so on, but also on the things that come further up in the stack that evolve around data, data content, and data structure. It is possible to connect the software to a couple of drone types/suppliers today, and tap data. The problems come afterward, when there are a handful of things that one needs to deal with, depending on who has delivered the data, and it does not work. It is not efficient and scalable, and it illustrates the need for standards so that this problem can be neglected. One must also notice that it is not only a need for standardization on the drones and IT systems, but also the equipment placed on the drones. A manipulator arm from company X should be connectable to drone A and vice versa.

For data, is standardization important for ensuring that it reaches the right users and external relevant regulations. Data governance with its principles is useful here. A property of a system is interoperability, which is based on simple interaction between systems across provider(s). Interoperability is central in open standards and will be useful in the development of this UID-control room, as it consists of so many different actors that have to interact (*samhandle*).

Making standards is not something that happens overnight, and in the meanwhile are there some possible solutions. One is to facilitate "open source" systems that are not dependent on specific programs or plug-ins, and that are accessible for every actor working within the field. Open-source programs make it possible to share solutions and one does not have to reinvent the wheel over and over, however, it must be flexible, modular, open, and adaptable. Another solution is to base the standards on the large actors' proprietary standards. The large companies have a lot of power in this and can thus set a standard for the industry, which should be further developed into a global standard.

There is probably a lot of work left undone when it comes to standardization, both in this case, but also in other industries. It might therefore be smart to take a look at what other industries with similar problems are doing, especially those who have control rooms, robots, drones, IT systems and software, and fleet management that is relatable to this case. Industry 4.0 also presents some standards with UPC UA and RAMI 4.0 that could be used in this case, or as inspiration and/or as a base.

When it comes to standardization in the O&G industry is the Subsea Wireless Group (SWiG), a network established in 2011, an important contributor. The group works with its members to define standards that facilitate interoperability between the users' subsea wireless technologies. They also engage in relevant standards bodies, encourage the integration of wireless technologies, and promote best practices across the industry (SWiG, 2021). The group is also involved in the universal docking station that is assumed used regardless of the type of drone in this thesis. It will be relevant to connect this group to the development of this control room. When it comes to control room/center design is ISO 11064 also a great tool to use, however it has its weaknesses, especially in this UID-control room case, which is discussed later in section 5.4.

It is clear that there must be developed standards (and support documents) in this area, which is also pointed out by several of the interview objects. However, which standards one should develop is dependent on existing standards and needs. It has not been made a deep dive into already existing standards on the area in this thesis, but it should be further investigated. Especially around the UID-control room case, to find out what is needed or can be further developed from other existing standards. Everything has been done before, but may have been done in different contexts and in different ways.

5.4 Human Factors and ISO11064

Using human factors as a center in this design-part of a control room for fleet management has been difficult, as it does not involve the clearest parts of the design with ergonomics and physical design. Necessary systems and functions for managing the control room's data streams are what has been in focus in this case, and without actually designing these systems, it is difficult to point to how the human factors should be integrated, except for designing it user-friendly with the human in the center, using the presented methods in the ISO and other support documents. This as the systems are dynamic and each has its own needs that must be accounted for. The nine principles that ISO 11064-1 presents are, however, useful to keep in mind when designing the process.

By performing the functional analysis and other work in this thesis we get an overview of what must be done in regards to the control room design, in addition to a basic estimation of time that needs to be put in the project. First when all systems are in place, and the drones can operate on a LoA with communication to the control room, can the physical room be built. ISO 11064-3 includes a lot of requirements here to how the room should be designed for optimal human work environment and performance.

This work also shows that it is important to clarify and define each task and sub-task from an early stage, to be able to evaluate the functions needed, as well as include the human factors in the process. However, we see that the a priori allocation is not necessarily the best way of distributing the functions.

5.4.1 Evaluation of ISO 11064

As presented in Table 4.1 did only 4 of 10 participants in the study have any knowledge of ISO 11064 - Ergonomic design of control centers. This was not surprising as the field of HFE is not as common and talked about as it may should be. Another aspect that must be taken into consideration when it comes to the ISO-standard, is that it from the early 2000s, and there has happened much since then, especially in the field of technology. However, are the principles presented still actual and valid today.

Placing this type of control room together with the ISO standard has not been easy, as the standard is not completely up to date, but also because it contains so many parts with multiple principles and requirements. This yields especially on the human-machine allocation of tasks, as this field has been growing greatly lately. That there exist support documents, such as EEMUA201, AJA, and CRIOP, to the standard is not surprising, given its complexity.

When it comes to autonomy is this something that ISO 11064-1 does not mention at all. Automation, or equivalent wording, is mentioned 15 times in the document, but automating tasks is not the same as giving a system some degree of autonomy. Even though the ISO mentions automation, does it not come with concrete plans for how to deal with the increased use of automated systems and how it should deal with the increased number of human failures as a consequence of automation. It only states that it must be determined if functions/systems to be allocated to humans can effectively be implemented using automation technology and that automation increases the risk for the operator losing its awareness as it no longer can identify what the system is doing. Designing a control room or center that depends on autonomy based on the ISO standard thus becomes challenging, as it does not take this into account. A revised version of the standard, or equivalent document, should take this into account in the future.

The function analysis, which is performed in some way in this thesis, is only a little part of what the standard recommends to perform of analysis and tasks for design of control centers. However, did it not fit completely into this case, as it is too early to say something on the operational modes of the controlled system (steady-state, normal transient, emergency/abnormal, and maintenance operation). It is also a factor that this control room manages a fleet of UIDs and not a facility (it can do both, but the focus here is only fleet management), making these modes not actual in the same way as it does for other "ordinary" control rooms. However, are the principles presented in part 1, which is the part in focus in this thesis, still actual for this type of control room, with the focus on human centered design and human factors.

As the problem case focuses on the design structurally and with regards to data flow, was delegating functions between humans and/or machines according to the ISO difficult, as many of the functions are dependent on data to be processed by machines/computers and drones to operate remotely with LoA. It is not as black and white to delegate them as the document presents, especially when the document does not say anything about data management. However, it is important to integrate and interact the functions between them both, as the ISO empathizes to some extent. Dynamic allocation of the functions, as introduced in chapter 2, is important for delegating the functions presented. This is because of the dynamic situations we have along with a complex and risky system where drones are operating on offshore equipment for oil and gas production, which, if something wrong happens, can cause severe damages for the environment in particular.

The combination of the ISO and integrated operations is also something that does not quite go hand in hand. IO, especially second generation, is about integration externally with other organizations, not only internally with regards to technology, processes, and people. The work processes that IO presents have a great impact on where and how people do their jobs, especially regarding technology improvements. The ISO 11064 standard however does not consider this, the development of useful technology, and hence does not focus on the possibility within this going forward. This is also the reason why the CRIOP [1], Crisis Intervention and Operability analysis, method was established. In short, does the method focus on human factors in relation to the operation and handling of

[1]CRIOP: https://www.sintef.no/projectweb/criop/the-criop-objective/

abnormal situations in offshore control centers, and to validate solutions and results (Johnsen et al., 2011). It thus complements what is seen as deficiencies in the standard when it comes to offshore needs.

After performing this study, it is clear that the ISO needs to be updated in light of new technology and its improvements. Its focus is the ergonomic design of control centers, but it is a bit well focused on the physical design of the room and talks about machines only as machinery and not computer systems. It is just as important to design the computer systems and other technical functions/systems with a focus on human factors and the use of user-oriented/centered programming. This yields especially for the principle of human-centered design that stands so strong in HFE. For function allocation, should it open for dynamic allocation, and draw out the problems and opportunities that autonomy brings to the control room. This can be done by presenting and/or discussing the LoA-table (or tables, there are many), showing what is shown in this thesis, that the needs for a system will change according to its tasks and use-case(s), and autonomy can help with this, but the systems and CROs must interact (*samhandle*) efficiently. This can only be obtained by designing the room with enough flexibility, as tasks will have different needs from CRO and machine.

When it comes to HMT is this a field that is undergrowth. Even though ISO 11064 is a design approach that considers HMT does it not correspond to the development in the field. The technological development we see today with the use of autonomy and AI shows us that new methods/alternatives are being established trying to deal with these new challenges, such as AI and black boxing, as well as the challenges that we see in ISO 11054. In systems engineering is processes for developing HMT requirements for specific systems being established. McDermott et al. (2018) has written a guide to help system developers design autonomy and automation that works in partnership with the human operator seamlessly. Here they present an interview guide and some HMT requirements that are meant to serve as a starting point and to be tailored or expanded upon through the use of the HMT system engineering methods (McDermott et al., 2018). In the military industry are they also seeing the effect of HMT with the use of robots and AI, together with the need to optimize HMT. UK Ministry of Defence (2018) has presented a set of deductions and insight that are judged most critical to guide strategy, policy, and force development for Defence and front-line commands, which offers guidance on factors that will determine advantage in an era of robotics and artificial intelligence (AI) during conflicts. This is among others, optimized HMT, trust and assurance for AI, and the potential of AI and protecting access, and is all about finding the optimal mix of manned and unmanned platforms while balance employment of human and machine cognition for various tasks (UK Ministry of Defence, 2018).

5.4.2 Development plan

One of the goals of this thesis was to develop a staircase model for the development of this control room over time. As presented in section 4.3 was this not possible given the time and information base of the student, as well as it at the same time fell a little bit outside the problem statement and its research questions. However, a list with elements that need to be developed has been evaluated, and we see that there is still a lot of work remaining for achieving success for this control room.

Chapter 6

Conclusion

The problem statement in this thesis was *"How to develop/design a control room for operations performed by a fleet of underwater drones (UIDs) in the petroleum industry?"*, focusing on the necessary technical functions and data-streams, as well as *samhandling* between different actors involved in the development, using human factor engineering as a base. As seen in the presented work, is designing such a UID-control room a challenging task, as it depends greatly upon autonomy and dynamic allocation of functions between human and/or machine. The UID-control room in itself is just one element in the capability stack model, but the work presented shows that it is dependent on the remaining elements in the stack, as they are co-existing in an ecosystem.

The major findings in the study show that a static allocation of necessary functions, found in the functional analysis, can not be done hence the ISO is too static. The systems and functions needed for each of the three use cases in focus here must have a degree of flexibility, as their level of autonomy will vary a lot based on technology development, but also the tasks themselves will have different human and/or machine interaction. A strategy for adaption of functions should therefore be in place for making this re-allocation process as clear as possible for the operators.

The study has also pointed out that there are two main concepts to be followed when designing this room dependent on whether the field operator is both controlling and observing the operations, or only observing and outsourcing the control to the drone suppliers which have their own proprietary control room. It has also shown that each inspection operation has its own needs and temporal condition, especially when looking at data streams and temporal rhythms. The support functions for the control room, primarily analyzing data and planning inspection rounds, have some other needs than the control room and the CROs, but is necessary to include (early) in the design phase, as they are important to the overall ecosystem.

The analysis from the interviews has shown that there are several design requirements for the development of specifications that need to be evaluated and considered. It has also shown that the development of a control room for fleet management of UIDs is possible, but demands further technological developments and resources. The idea of placing drones on the seabed and give them the janitor role is a sought-after need that offers many (new) opportunities, and the willingness to develop the necessary technology for this to be achievable exists in the industry.

When it yields for the human factors approach, we see that in this early stage of the design process is it difficult to allocate functions when having different levels of autonomy which affects the operations, but that the principles presented in ISO 11064-1 and the focus on human centered design stands strong. However, have we also seen that the ISO for ergonomic control room design has its weaknesses and can be considered as outdated on several aspects, as it is too static and is from the early 2000s, and thus does not take into account the great developments in technology that have taken place up until today. Another area that has not been talked about that much here, but in EEMUA201, is the training of the personnel. This is also something that should be included and is important for the human factor approach. It is also important in terms of maintaining the understanding of the situation and being able to be on the alert when something unexpected happens. Whether the control room should have a separate training room, or the room is a part of a control center that has a common training room, is something that must be decided by the operator. However, if there are proprietary control rooms must the drone supplier take on this responsibility.

Apart from the design criteria and concepts presented, should it also be mentioned that this type of control room is generic, and can be used in other industries/contexts. The functions needed can be a little bit different, but the main structure is workable.

6.1 Further work and Opportunities

There still remains much work designing this control room for fleet management with UIDs, and it yields for all key players in the ecosystem. This thesis has only taken into account one small part of the design and provided some choices that the operator(s) must make structurally. Some examples of further work and/or investigations on a more detailed level are already mentioned in chapter 4 and chapter 5, but overall work to be performed is still a lot.

First of all, must the field operator/owner wishing to develop and design this control room take some strategic choices and gather relevant partners who are willing to assist with resources. Business models and strategies must also be clear in regards to the strategic investment and goals. When it comes to technology development is there still a lot of work that must be done in light of this control room. Autonomy on underwater drones needs further testing and improvements, and gain enough trust to operate on the subsea facility without direct human control.

There must also be designed software for handling the huge amounts of data that are accumulated by the sensor platforms, as well as developed good IT systems for managing the data streams and for communication. Here must the functions presented be evaluated and implemented, and it is also used for a dynamic allocation between them with regards to the level of autonomy on the drones. ISO 11064 consists of seven parts, and this only takes into consideration part 1. The rest of the standard should also be evaluated and used for the design and development of this control room. This yields both physical with furniture and equipment, as well as technological solutions.

Lastly, methods within human-machine teaming should be further developed. Autonomous systems will mold more and more of the technological development further, and there is a need for making designs that optimizes HMT. To do so, one needs standards, guides, requirements, etc. that contribute to this need. Some work has already been done, but there is still a long way to go.

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Appendix

A Approval from NSD

MELDESKJEMA FOR BEHANDLING AV PERSONOPPLYSNINGER   Norsk   Ingrid Folstad

NSD sin vurdering

Skriv ut

Prosjekttittel
Funksjonsanalyse for design av et kontrollrom for en UID-flåte i O&G-industrien

Referansenummer
829957

Registrert
16.02.2021 av Ingrid Folstad - ingrifol@stud.ntnu.no

Behandlingsansvarlig institusjon
Norges teknisk-naturvitenskapelige universitet / Fakultet for ingeniørvitenskap / Institutt for geovitenskap og petroleum

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)
Vidar Hepsø, vidar.hepso@ntnu.no, tlf: 48034803

Type prosjekt
Studentprosjekt, masterstudium

Kontaktinformasjon, student
Ingrid Folstad, ingrifol@stud.ntnu.no, tlf: 94872381

Prosjektperiode
15.01.2021 - 10.06.2021

Status
18.02.2021 - Vurdert

Vurdering (1)

18.02.2021 - Vurdert
Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg den 18.02.2021, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra NSD før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige kategorier av personopplysninger frem til 10.06.2021

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake.
Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a.

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

· lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
· formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke behandles til nye, uforenlige formål
· dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
· lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: åpenhet (art. 12), informasjon (art. 13), innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), og dataportabilitet (art. 20).

NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.
Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og/eller rådføre dere med behandlingsansvarlig institusjon.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!
Tlf. Personverntjenester: 55 58 21 17 (tast 1)

B Interview Information for Subjects

Informasjonsskriv til intervjuobjekter for masteroppgave
Hei, mitt navn er Ingrid og jeg studerer sisteåret på mastergraden Ingeniørvitenskap og IKT på NTNU. For tiden skriver jeg på en masteroppgave med problemstillingen: «Hvordan utforme/designe et kontrollrom for arbeidsoperasjoner utført av en flåte med undervanns-droner (UIDer) i O&G-industrien?», hvor målet med oppgaven er å gjennomføre en system/funksjonsanalyse for et UID-kontrollrom. Jeg tar kontakt etter tips fra master-veilederen min, og håper at du kunne tenke deg å være med som et intervjuobjekt i dette prosjektet. Det det innebærer for deg er et intervju over en digital flate (fortrinnsvis Teams) på maksimalt en times tid. Veilederen min er Vidar Hepsø i Equinor/Professor 2 på NTNU innenfor BRU21: Research and Innovation Program in Digital and Automation Solutions for the Oil and Gas Industry (https://www.ntnu.edu/bru21).

Oppgaven er rettet mot human factor engineering/ergonomics, men med et fokus på hvilke funksjoner/systemer som er nødvendige på den (data)tekniske siden, og ikke den generelle utformingen/designet av selve rommet.

Av arbeidsoperasjoner som dronene vil utføre er det i dette prosjektet to stykker: sjekk/kontroller og rapporter (rask avklaring av en oppsatt feil som har oppstått på anlegget), og planlagt inspeksjon på subsea anlegg. Flåten av droner kan bestå av ulike typer droner/sensorplattformer (f.eks. AUV, ROV, eller kombinasjon av disse) med diverse utvalg av sensorer og utstyr, og er tenkt stasjonert på havbunnen.

Spørsmålene i intervjuet vil derfor være sentrert rundt følgende forskningsspørsmål:

- Hvilke funksjoner/systemer er nødvendige i kontrollrommet, spesielt rettet mot maskin og menneske?
- Hvordan håndtere data- og informasjonsstrømmene, spesielt rettet mot dronenes arbeidsprosesser?
- Hvordan legge til rette for god samhandling mellom de ulike partene involvert i operasjonene?

Resultatene fra intervjuene er tenkt brukt til utforming av en utviklingsplan for et UID-kontrollrom, hvor en ser på konseptet over tid, gjerne med utprøvinger/piloteringer slik at en får en modningsfase og et godt produkt over tid. Resultatene kan også brukes til utforming av framtidens kontrollrom innenfor andre områder.

Information for interview subjects for master thesis
Hi, my name is Ingrid and I am studying at my last year at the master's program Engineering and ICT at NTNU. I am currently writing my master thesis with the following problem description: "How to develop/design a control room for operations performed by a fleet of underwater drones (UIDs) in the petroleum industry?", where the goal is to perform a system/function analysis for a UID control room. I am reaching out to you after a tip from my supervisor, and I am hoping that you would like to take part in this project. Taking part in the project includes an interview (preferability digital on Teams) for about an hour. My supervisor is Vidar Hepsø in Equinor/Professor 2 at NTNU working on BRU21: Research and Innovation Program in Digital and Automation Solutions for the Oil and Gas Industry (https://www.ntnu.edu/bru21).

The thesis is aimed at human factor enginerring (HFE)/ergonomics, but focuses on which functions/systems that are necessary on the technical side, not the general design of the room itself.

When it comes to work processes performed by the drones, we are focusing on these two in this project: check and report (e.g. quick clarification of an error that has occurred at the plant), and planned inspection on a subsea facility. The fleet of drones can consist of different types of drones/sensor platforms (e.g. AUV, ROV, or a combination of these), with various selection of sensors and equipment, and is intended to be stationed on the seabed.

The questions in the interview will therefore be centered around the following research questions:

- Which functions/systems are necessary in the control room, especially aimed at machines and humans?
- How to handle the data and information flows, especially aimed at the drones' work processes?
- How to facilitate good cooperation between the various parties involved in the operations?

The results from the interviews are intended used to design a development plan for a UID control room, where one looks at the concept over time, preferably with pilots so that one gets a maturation phase and a good product over time. The research can also be used in design of other kinds of control rooms in the future.

C Statement of Consent

Based on NSD's template.

Vil du delta i forskningsprosjektet «Design av et kontrollrom for arbeidsoperasjoner utført av en flåte med undervannsdroner (UIDer) i O&G»?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å **gjennomføre en system/funksjonsanalyse for et UID-kontrollrom.** I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Resultatene fra intervjuene er tenkt brukt til utforming av en utviklingsplan for et UID-kontrollrom, hvor en ser på konseptet over tid gjerne med utprøvinger/piloteringer slik at en får en modningsfase og et godt produkt over tid. Flåten med UIDer skal i hovedsak utføre to arbeidsoperasjoner: sjekk og rapporter, samt planlagt inspeksjon.

Problemstillingen lyder som følgende: *«Hvordan utforme/designe et kontrollrom for arbeidsoperasjoner utført av en flåte med undervannsdroner (UIDer) i O&G-industrien?»*, spisset med følgende tre forskningsspørsmål:

- Hvilke funksjoner/systemer er nødvendige i kontrollrommet, spesielt rettet mot maskin og menneske?
- Hvordan håndtere data- og informasjonsstrømmene, spesielt rettet mot dronenes arbeidsprosesser?
- Hvordan legge til rette for god samhandling mellom de ulike partene involvert i operasjonene?

Prosjektet er en masteroppgave utført av en student på studieprogrammet Ingeniørvitenskap og IKT ved NTNU: Norges teknisk-naturvitenskapelige universitet.

Hvem er ansvarlig for forskningsprosjektet?
Institutt for geovitenskap og petroleum (IGP) ved NTNU er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?
Du er plukket ut til å delta basert på din arbeidsstilling/posisjon, som ses på som relevant i dette prosjektet.

Hva innebærer det for deg å delta?
Hvis du velger å delta i prosjektet, innebærer det et digitalt intervju (fortrinnsvis på Teams) med studenten, med en varighet på en liten time.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- Masterstudenten og hennes veileder vil ha tilgang på informasjonen/materialet
- Navnet og kontaktopplysningene dine vil studenten erstatte med en kode som lagres på egen navneliste adskilt fra øvrige data

- Angående intervjuopptak: disse vil bli transkribert i løpet av én uke (7 dager). Etter transkribert intervju, vil video-opptaket bli slettet. Alt av materiale vil lagres lokalt på studentens laptop.

Deltakere vil ikke kunne gjenkjennes i publikasjonen, ettersom målet her er å undersøke hvilke funksjoner som er nødvendige i utformingen av kontrollrom med UID-flåte. Kun informasjon om deltakers bakgrunn og stilling vil bli publisert.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er planlagt å være 10.juni 2021. Etter dette vil all data slettes.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:
- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få rettet personopplysninger om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Institutt for geovitenskap og petroleum ved NTNU har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:
- *Vidar Hepsø, professor II ved institutt for geovitenskap og petroleum, NTNU. vidar.hepso@ntnu.no, +4748034803*
- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Vidar Hepsø

Prosjektansvarlig
(Forsker/veileder)

Ingrid Folstad
Student

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *«Design av et kontrollrom for arbeidsoperasjoner utført av en flåte med undervannsdroner (UIDer) i O&G»* og har fått anledning til å stille spørsmål. Jeg samtykker til:

☐ å delta i intervju

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet, rundt 10.juni 2021.

(Signert av prosjektdeltaker, dato)

D Interview Guide in Norwegian

Introduksjon:
Målet er å bli litt kjent før intervjuet starter (oppvarming). Start med å fortelle kort om prosjektet/casen og hvordan du skal behandle personlig informasjon i lys av samtykkeskjemaet. Be så intervjuobjeket fortelle litt om seg selv og sin karriere/kompetanse innenfor sitt/dette fagfeltet, utdanningsbakgrunn, år med erfaring og nåværende stilling, etc.

Kontrollrom må designes etter en rekke krav fra myndigheter og internasjonale standarder, og i dette tilfellet er ISO11064 – ergonomisk design for kontrollsentere, veldig relevant og viktig, og blir brukt som et utgangspunkt i denne oppgaven.

Er du kjent med innholdet i disse standardene eller guidene, og hvordan forholder du deg til disse/hva er ditt forhold til disse? Hvis nei: fortell litt om standardens innhold og intensjon.

1. Funksjoner: Menneske vs. Maskin
Fordeling (allocation) av funksjoner til maskiner og/eller mennesker er noe som står sentralt i del 1 av ISO 11064, og som det fokuseres på i dette prosjektet. Maskiner er gjerne mer egnet for routine monitoring, high accuracy eller repeterende oppgaver. Mennesker er bedre på oppgaver som krever tilpasning, integrering og generalisering, strategi og planlegging.

Vi har en flåte med droner som er utstyrt med diverse utstyr og sensorer. Disse blir brukt i arbeidsprosessene og samler opp data som sendes til kontrollrommet i real-time eller ved docking. Hvordan en skal ta i bruk denne datastrømmen, altså outputen fra sensorplattformene, er en del av casen. Her går det på hvilke funksjoner/systemer en har behov for.

De neste spørsmålene handler derfor om hvilke funksjoner bør tildeles maskin og menneske, samt integreres, gjerne på en slik måte at det skapes utfordrende, interessante og tilfredsstillende arbeidsplasser, samtidig som sikkerhet og andre krav oppfylles.

Relevante spørsmål å stille:

- Hvilke funksjoner/systemer spesielt er det som trengs i et slik UID-kontrollrom, for å kunne utvikle et operativt og skalerbart kontrollrom? Gjerne sammenlignet med de kontrollrommene som finnes i dag.
- Hvilke funksjoner kan/skal/bør utføres/kontrolleres av mennesket?
- Hvilke funksjoner kan/skal/bør utføres/kontrolleres av maskiner, og i hvor stor grad skal det være rom for feiltolerant (error-tolerant) maskindesign?
- Hvilke interaksjoner mellom maskin og menneske vil en trenge/ha behov for?
- Du sier at kontrollrommet trenger følgende [xxx] funksjon(er). Hva ser du på som de mest kritiske elementene en trenger å utstyre dronen/kontrollrommet med for å innfri til disse?

2. Teknologi i kontrollrom
Ny teknologi utfordrer oss stadig mer. Utvikling og anvendelse av for eksempel maskinlæring (ML) og kunstig intelligens (AI) kan være med på å prege alle tilfeller av beslutningstaking (decision making), -prosesser og utførelse.

Relevante spørsmål:

- Hvilken teknologi er nødvendig eller relevant å ha med i kontrollrommet, og hvorfor? Eks. Simulering av oppdrag for navigasjonshjelp i uklart vann (digital tvilling)?
- Hvordan sikrer man at mennesket fortsatt vil være en del loopen/prosessen (slik at teknologien ikke tar overhånd)? Det må være en attraktiv/engasjerende jobb for mennesket og den må kunne gripe inn ved behov.

3. Arbeidsprosesser til UID-flåten, datastrøm Som nevnt er kontrollrommet i denne casen for (fjern)styring av en flåte med undervannsdroner som skal gjennomføre sjekk/kontroller og rapporter, og planlagt inspeksjon på subsea-anlegg. Intensjonen er at alt skal styres fra land. De neste spørsmålene sentreres derfor mer rundt dronene, data og kommunikasjonen til land.

- Hvordan kan en sørge for at en har kontroll på alle dronene i flåten til enhver tid, gitt at en har behov for det?
- Hvordan kommunisere og overvåke dronene som er stasjonert på havbunnen– hva er det behov for?
- I full autonom modus kan en miste/få redusert kommunikasjon underveis eller mellom bestemte punkter. Kan en stole på at dronen gjør det arbeidet den er satt til uten kommunikasjon?

Det vil være to strømmer av informasjon/data (i denne casen)– en for housekeeping data (tilstandsdata) og en for det som går på sensorbiten med kobling til land. Housekeeping (health monitoring) er en informasjonsstrøm som sier noe om tilstanden på dronen, f.eks. om den lader eller ikke. Den andre strømmen vil ta for seg up- og down-load av data fra sensorene samt oppdra.

- Hvordan håndtere data- og informasjonsstrømmene mellom anlegg/flåten og land/kontrollrommet?
- Hva kan/skal håndteres i sanntid og hva kan håndteres ved docking?
- Hva slags housekeeping-data er det egentlig behov for?
- Trenger dataen du trekker fram å visualiseres eller vises på noe vis i kontrollrommet/hos andre parter?
- Når det gjelder de to arbeidsprosessene, hvordan burde de gjennomføres og hvilket behov har mennesket for involvering i disse?
- Hvordan sørge for (god) dataflyt og kommunikasjon? Hvilke funksjoner trengs for dette?
- Hvem og hva trengs, og hvem eller hva gjør hva (av arbeidsprosesser)? F.eks. utføres inspeksjonsoppdrag gjennom direkte kontroll og styring fra kontrollrommet, eller er det noen form for autonomi her? må dronene aktivt tildeles sjekk og rapporter-oppdrag, eller er dette noe en kan automatisere?

4. Samarbeid og håndtering av data
Et kontrollrom av dette slag vil kreve samarbeid mellom ulike/flere aktører/parter. Eksempelvis vil en leverandør stå for dronen(e), en for det subsea anlegget, en for planlegging og analyse, og en for utførelsen av selve operasjonen (kontrollrommets operatør(er)), samt samarbeid med andre kontrollrom.

- Hvordan legge til rette for god samhandling mellom de ulike partene involvert i operasjonene? Er det noen funksjoner her som er mer essensielle enn andre? (Internt vs. Eksternt)
- Hvordan skal/bør ulike aktører jobbe mtp. de informasjonsstrømmene en har tilgjengelig og datahåndteringen av disse? Samt hvordan arbeide inn mot de arbeidsprosessene som skal gjennomføres?

5. Opplæring og kompetanse
Kompetansen til ROV-operatører i dag er veldig høy, og det å operere en drone i det gitte miljøet er noe som krever god forståelse og erfaring. Det krever en del spesielle egenskaper og spesialisert kunnskap og kompetanse.

- Hvilken type opplæring, trening og kompetanse er nødvendig for kontrollromoperatøren(e), og i hvor stor grad burde kontrollromoperatøren ha kjennskap til hvordan de tekniske systemene fungerer?
- Teknisk og/eller operativ kompetanse - mer av den ene enn den andre?
- Trenger operatøren å forstå prinsippene bak infrastrukturen til både system og flåte, eller kun operere?
- Hvilke ferdigheter burde operatøren ha?
- Sammenlignet med dagens ROV-piloter; hvilken (ekstra) kompetanse er nødvendig for en pilot/operatør i dette kontrollrommet (med en flåte med droner på havbunnen)?
- Hvilken forståelse for autonomi er nødvendig for operatøren å ha?

6. Hva ser du på som naturlige utviklingstrekk for utviklingen av et slik kontrollrom?

7. Hva ser du på som den største utfordringen i utviklingen av et slik kontrollrom, gitt casen?

Avslutningsvis:

- Spørre om det er noe deltakere lurer på videre eller om den har noen andre kommentarer
- Er det mulighet for oppfølgingsspørsmål/undersøkelser dersom det er behov (på mail) i ettertid?
- Takk for tiden og hjelpen

Ingrid Folstad

Master's thesis in Engineering and ICT

NTNU
Norwegian University of
Science and Technology