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Charlotte Hjelmseth Larssen

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Economics and Management
Dept. of Industrial Economics and Technology Management

DARWIN Resilience Management Guidelines for Everyday Operations in the Petroleum Industry

Remote Operation of Underwater Inspection Drone

Master's thesis in Health, Safety and Environment

Supervisor: Ivonne Herrera and Vidar Hepsø

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Summary

The objective of this thesis was to analyze a chosen operation case within the petroleum industry, to assess where the resilience management guidelines could be applied to improve the resilience of the operation. The case that was addressed is the use of remotely operated underwater inspection drones (UIDs) on subsea installation on the Norwegian Continental Shelf. A set of capability cards from the Darwin Resilience Management Guidelines (DRMG) were selected and adapted for application to the case. These are guidelines for improvement of the ability to anticipate, monitor, respond, adapt, learn and evolve, to operate efficiently in the face of crises. This guidelines have previously been applied to aviation and healthcare. The following problem statement was addressed;

- *How can the DRMG be adapted and applied to improve resilient management for remote operation in the petroleum industry?*

To address the problem statement and achieve the objective, a mix of analytical methods was applied to create an understanding of the operation in context of the industry and its external factors. Triggering questions from the capability cards in the DRMG where selected based on the findings from the analytical methods, and the picture they created of the operation. This was an initial attempt at adapting the capability cards. Further, these questions where tested, by applying them through a set of interviews with chosen leaders from the oil company. This to reveal whether the adapted triggering questions could be applied to improve resilience in the operation, and whether the adapted triggering questions require revision.

The results show that the triggering questions can stimulate helpful reflections bringing tactic knowledge from the organization that could be used as input for the development of measures and actions, that when implemented could help improve the resilience capability of the operation. The adaption was made for a specific case, and the resulting questions might therefor not be generalizable for other operations. However, the method of adapting the DRMG for application could be applied for other operations and processes to form triggering questions applicable for various cases. The results also show that the triggering questions adapted in the thesis would need to be further revised for them to have the optimal effect.

Sammendrag

Målet med denne avhandlingen var å analysere en valgt case innen petroleumsindustrien, for å vurdere hvor resiliens styring kunne benyttes for å forbedre resiliens kapabiliteter i operasjonen. Casen som ble behandlet er bruken av fjernstyrte undervanns inspeksjons droner (UID) ved undervannsinstallasjoner på norsk sokkel. Et sett med kapabilitets kort fra Darwin Resilience Management Guidelines (DRMG) ble valgt og tilpasset for anvendelse i casen. Dette er retningslinjer for forbedring av evnen til å forutse, overvåke, respondere, tilpasse, lære og utvikle seg, for å operere effektivt i møte med kriser. Disse har tidligere blitt benyttet for luftfart og helsesektoren. Følgende problemstilling ble adressert;

- *Hvordan kan DRMG tilpasses og benyttes for å forbedre resiliens i fjernstyringsoperasjoner i petroleumsindustrien?*

For å løse problemstillingen og oppnå målet, ble ulike analysemetoder brukt for å etablere en forståelse av operasjonen i kontekst av industrien og dens eksterne faktorer. Spørsmålene fra kapabilitets kortene i DRMG ble valgt basert på funnene fra analysemetodene, og bildet de dannet av operasjonen. Dette var et initierende forsøk på å tilpasse kapabilitets kortene. Videre ble disse spørsmålene testet, ved å benytte dem gjennom et sett av intervjuer med utvalgte ledere fra oljeselskapet. Dette for å avdekke om de tilpassede spørsmålene kan brukes for å forbedre resiliens i operasjonen, og om de tilpassede utløsende spørsmålene krever revisjon.

Resultatene viser at spørsmålene kan stimulere til nyttige refleksjoner og belyse taus kunnskap i organisasjonen. Dette kan videre benyttes som input for videre utvikling av tiltak og handlinger, som når implementert, kan bidra til å forbedre operasjonens motstandsevne. Tilpasningen ble rettet mot en spesifikk case, og de resulterende spørsmålene er derfor ikke generaliserbare for andre operasjoner. Imidlertid kan metoden for å tilpasse DRMG benyttes for operasjoner og prosesser for å tilpasse spørsmål for forskjellige tilfeller. Resultatene viser også at de utløsende spørsmålene som er tilpasset i oppgaven, må revideres ytterligere for at de skal ha størst mulig effekt.

Preface

This report is the result of the master thesis by Charlotte Hjelmseth Larssen and Emilie Låstad, two students completing a Master of Science in Safety, Health and Environment at the Norwegian University of Science and Technology (NTNU) in Trondheim. The master thesis consider the possibility to adapt and implement Darwin resilient management guidelines to everyday operation of remotely operated underwater inspection drones (UIDs) in the oil and gas sector. As a basis for the thesis a project assignment focused on resilience in remote operation of platforms in the oil and gas industry was conducted during the fall semester 2019.

We would like to extend a thank you to our supervisor Ivonne Herrera, for guidance and feedback on the thesis work. We would also like to thank our co-supervisor Vidar Hepsø for feedback and guidance on the case and the thesis work. Further, we would like to thank Sturle Næss for input on the thesis, and the interview subjects for their time and their feedback on the work. Lastly, we would like to thank the personnel at NTNU AMOS - Centre for Autonomous Marine Operations and Systems, for guidance and collaboration during the semester.

Originally the final deadline for the thesis was set to the 06/11/20, but due to Covid-19 the institute extended the deadline to the 07/02/20. The virus has created some challenges under the way, such as a closed campus, Charlotte's four week quarantine, and Emilie had her toddler home due to a closed kindergarten. We would therefore also like to extend a thank you to Noah Sebastian, for mostly being a patient toddler, letting his mum work on her thesis.

Trondheim, July 1, 2020

Emilie Låstad

Charlotte Hjelmseth Larssen

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Clarification of Concepts and Abbreviations

Concepts	Description
Automation	The use of machines and computers that can operate without needing human control (Cambridge Dictionary, 2019a)
Autonomy	The word autonomy comes from the greek word autonomos, which is a combination of autos and nomos, meaning “self” and “law”. Combined, they are understood to mean “having its own laws”. The word autonomy is most commonly used to explain independence of countries and people, and describes freedom from external control or influence (Oxford Living Dictionaries, 2017)
Capability Cards	The building blocks of the guidelines. CCs propose specific interventions in order to develop and enhance specific resilience management capabilities. They are built based on knowledge captured through literature review and interviews, and revised by incorporating operational perspectives. (DARWIN, 2018c)
Critical Infrastructure	The physical and information technology facilities, networks, services and assets that, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments in EU countries (EPCIP, 2006)
Complex adaptive systems	Systems that have the capacity to self-organize and adapt based on past experience, and are characterized by emergent and non-linear behaviors and inherent uncertainty (Miller and Page, 2009).
Complex systems	A system in witch a perfect understanding of the individual parts does not give a perfect understanding of the system (Miller and Page, 2009).
DARWIN resilience management guidelines (DRMG)	The DRMG are evolving guidelines, designed to improve the ability of stakeholders to monitor, anticipate and learn from crises, and thereby allow them to adapt and respond and more effective and operate more efficiently during disasters (Herrera et al., 2019).
Leading indicators	Leading indicators is a measure that give a prediction on future development, rather then historical indication (Cambridge Dictionary, 2020b).

Concepts	Description
Goal conflict	Conflicts between the organizations goals (DARWIN, 2018a)
Indicator	A measure of the current performance or a change (Cambridge Dictionary, 2020a)
Resilience	The ability to recover or restore after being stretched or pressed (Cambridge Dictionary, 2019b).
Remote operations	To operate a system over a distance (Lichiardopol, 2007). This involves monitoring and managing processes from a remote location, using different sensors and equipment for collecting and transmitting data for processing (Saeverhagen et al., 2013).
Sociotechnical System	A sociotechnical system is a systems where people play an important role in, or has relations to the system. These systems are comprised of a combination of different elements such as; hardware,software, man, management and organization, and the surrounding environment (Rausand, 2011).

Abbreviations	Description
AUV	Autonomous Underwater Vehicle
CC	Capability Card
CI	Critical Infrastructures
CrV	Compliance vs. Resilience
DRMG	Darwin Resilience Management Guidelines
EU	European Union
FPSO	Floating Production, Storage and Offloading
FRAM	Functional Resonance Analysis Method
HMT	Human Machine Teaming
HSE	Health, Safety and Environment
IO	Integrated Operations
LOA	Level of Autonomy
MTO	Man, Technology and Organization
MMS	Man-machine system
NGOs	Non-Governmental Organizations
RE	Resilience Engineering
ROC	Remote Control Room
ROV	Remotely Operated vehicle
SWOT	Strengths, Weaknesses, Opportunities, Threats
UUV	Unmanned Underwater vehicle
WAD	Work as done
WAI	Work as imagined

Chapter 1

Introduction

Today's risk picture is diverse. Companies and industries have to face a range of risks. The World Economic Forum (WEF) have defined a global risk as; *an uncertain event or condition that, if it occurs, can cause significant negative impact for several countries or industries within the next 10 years* (WEF, 2020). In their annual global risk report 2020, they have identified risks in the categories economic, environmental, geopolitical, societal and technological risks (WEF, 2020).

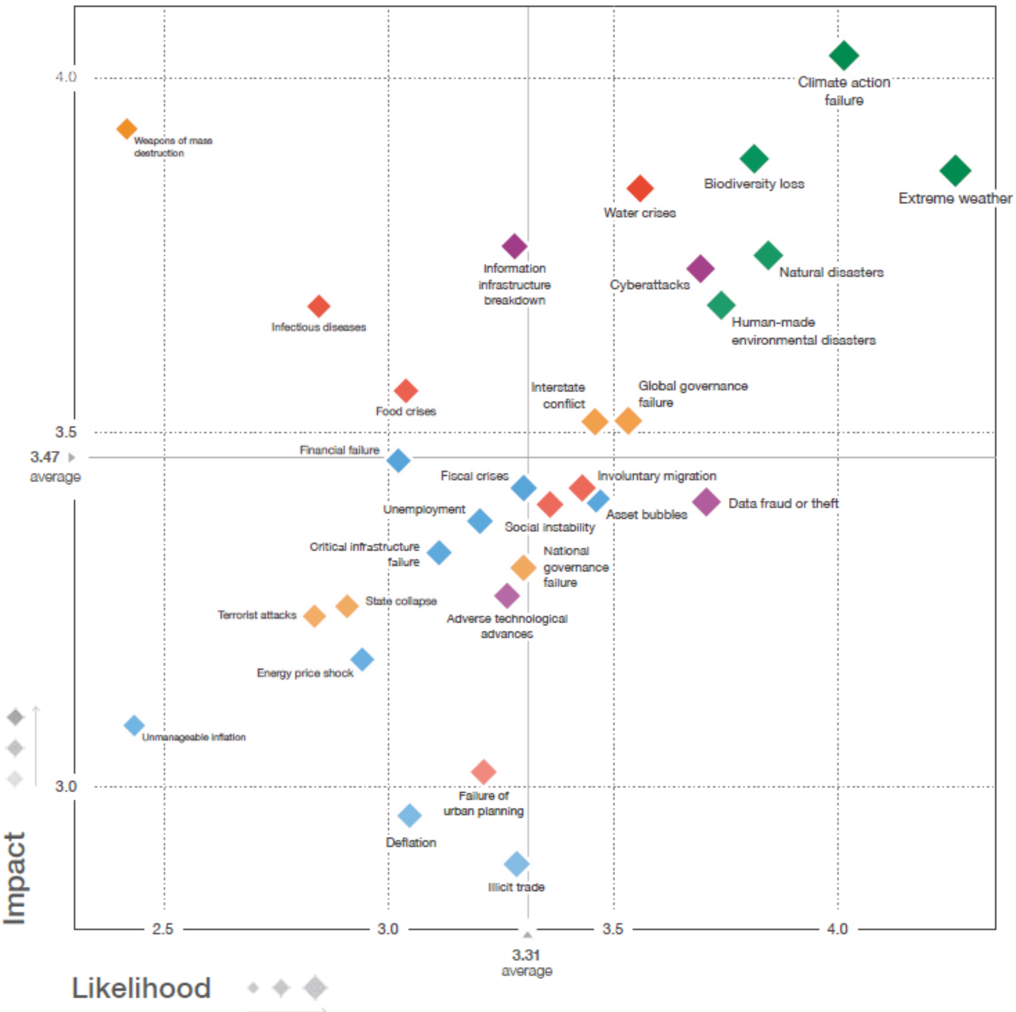

Figure 1.1: Global Risk Landscape (WEF, 2020)

Figure 1.1 shows a global risk landscape, constructed based on a global risk perception survey. Risk perception can be defined as; *Beliefs about potential harm or the possibility of a loss. It is a subjective judgment that people make about the characteristics and severity of a risk* (Darker, 2013). The risk landscape shows a variation of risks within different categories. Risks within the environmental and technological categories are viewed to have quite high impact, and are also considered to have a higher likelihood.

The world is also gradually getting more complex and interconnected. A system in which a perfect understanding of the individual parts does not give a perfect understanding of the system, is a complex system (Miller and Page, 2009). The risks the world is facing get more global consequences, as they span over multiple borders and industries. In the global risk perception survey by WEF (2020), the participants were also asked to give six pairs of global risks with the strongest connection. Based on the feedback, an interconnection network was constructed, as can be seen in figure 1.2. The lines show connections, while the size of the diamond show the number and strength of connections.

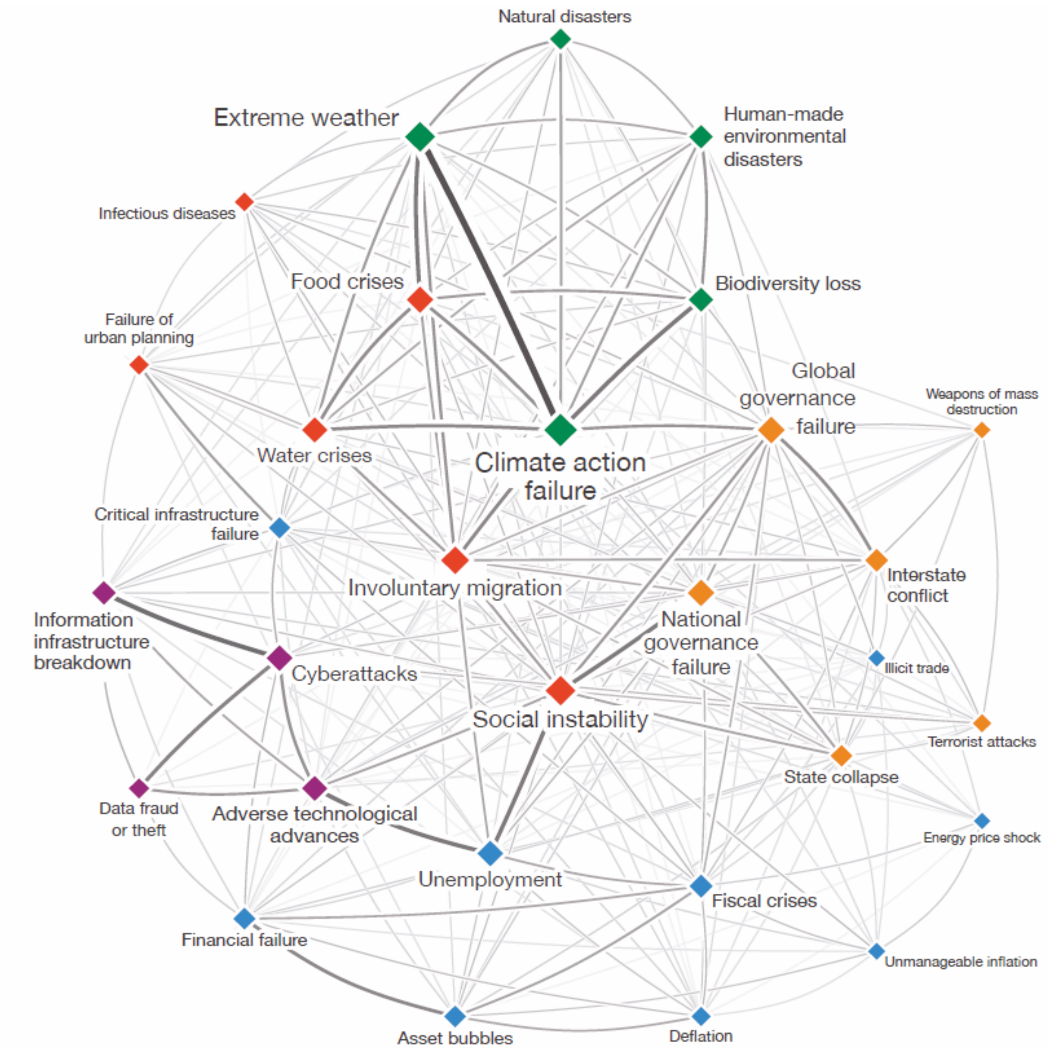

Figure 1.2: Interconnections between risks (WEF, 2020)

The petroleum industry is also affected by the developing risk landscape. The environmental risks gives more extreme weather conditions, which affect the operations that are already located in exposed areas (Miljødirektoratet, 2018). The geopolitical risks affect the companies as their business crosses borders, and changes local and global governing. Economically the industry has gone through big fluctuations the latest years. Technological risks become more and more relevant for all industries. The technological development in industries is rapid. The increasing digitalization has lead to a focus on these risks both on governmental and industry level. NSM (2019) and Deloitte (2019) have both released reports that highlight the new emerging risks related to digitalization. Technological solutions can help companies reduce costs, and also contribute to reduce environmental impacts. The pressure to always produce more efficiently, cost efficient, environmentally friendly and safe, drives the technological development in the industry. Remote operation and automation have been introduced into production. This also becomes necessary to a higher degree, as the industry is exploring more remote areas with deeper waters. The technological solutions constitute many opportunities for the industry, but also poses new risks and challenges. The tight couplings in systems, and between systems, means that even small variabilities in everyday operations could possibly lead to events with big propagating consequences.

The increasing degree of complexity and interactions in the industry, pose a challenge for modern risk management. The current management philosophies and methods need to adapt to the new challenges, where there is a high degree of uncertainty and complexity. These new challenges can potentially be addressed by resilience (Herrera et al., 2018). For this thesis, the DARWIN resilient management guidelines will be adapted and applied in an effort to improve the resilience of remote- and autonomous operations in the petroleum industry.

1.1 The DARWIN Project

The DARWIN project is a research project developed as a part of Horizon 2020, EUs Research and Innovation program. The purpose of the program is to strengthen Europe's position within future scientific and industrial development. With the modern risk picture in mind, a central area of this scope is to strengthen the critical infrastructures ability to tackle societal challenges (Horizon2020, na). With a focus on crisis management, both expected and unexpected crisis, caused by man-made or natural disasters, the DARWIN project aim to strengthen this ability.

Through the DARWIN project, the DARWIN Resilient Management guidelines (DRMG) have been developed. The objective of the guidelines is to improve the ability to anticipate, monitor, respond, adapt, learn and evolve, to operate efficiently in the face of crises (Herrera et al., 2019). The guidelines are not prescriptive, but allow organizations to consider their management procedures and practices from a resilient management view.

The guidelines are divided into 6 themes, which are further divided into 13 topics. These topics are captured through a set of Capability Cards (CCs). CCs propose interventions for developing and enhancing resilience management capabilities. The capability cards are further explained in section 2.8.1. In this master thesis, the aim is to adapt and apply the DRMGs to remote operations in the oil and gas industry. To our knowledge, the first time this is done for this domain.

1.2 Case Description

Equinor, the biggest operator on the Norwegian continental shelf (Smith-Solbakken et al., 2019), are working on a new subsea docking station for underwater inspection drones (UIDs). The docking station will make it possible to charge the UIDs subsea. During charging, drones can upload mission data, and download new commands. This way the UIDs can ”live” on the seabed. The subsea docking station removes the need for an operator and a control room on the platform. The solution also reduces the downtime of the UIDs caused by weather conditions that hinder operation, which typically is a problem with traditional ROV (remotely operated vehicle) operations.

Intervention and inspection UIDs can perform inspections of installations on the seabed, and perform maintenance and repairs where it is necessary. The UIDs can be monitored and remotely controlled from a control room onshore. The thesis will consider a specific envisioned everyday operation of inspection of a subsea installation, at the Åsgard petroleum field. On this field you find Åsgard A, a floating production, storage and offloading (FPSO) for production of oil and natural gas, Åsgard B, a floating platform for gas and condensate production, and Åsgard C, a ship for storage of condensate (Hagland, 2019b). The oil and gas field is in the operation phase.

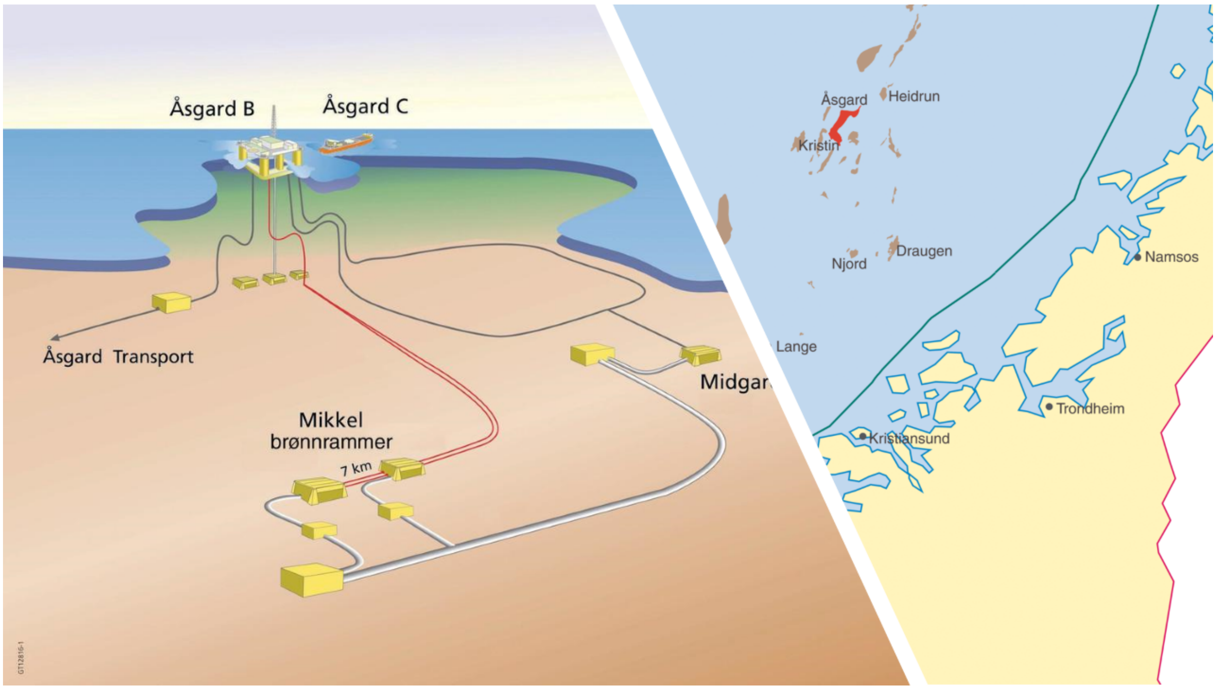

Figure 1.3: The Åsgard B field (Hagland, 2019a), (Hagland, 2019b)

For the thesis, the focus will be on one specific contract model. This model involves inspections being carried out on the subsea installation by a contractor on request from the oil company. The inspections can be pre-planned, and to some degree pre-programmed. The drones are operated and owned by a contractor, and will be controlled from the contractors control room, situated onshore. Mission planning and execution is done in collaboration with, and with approval from the oil company. The actors involved in the operation are presented in figure 1.4. This contract model is selected, as it seems the most likely solution for early use of UIDs on the oil and gas fields. There are other possible contract models. These could be relevant for assessment at a later stage.

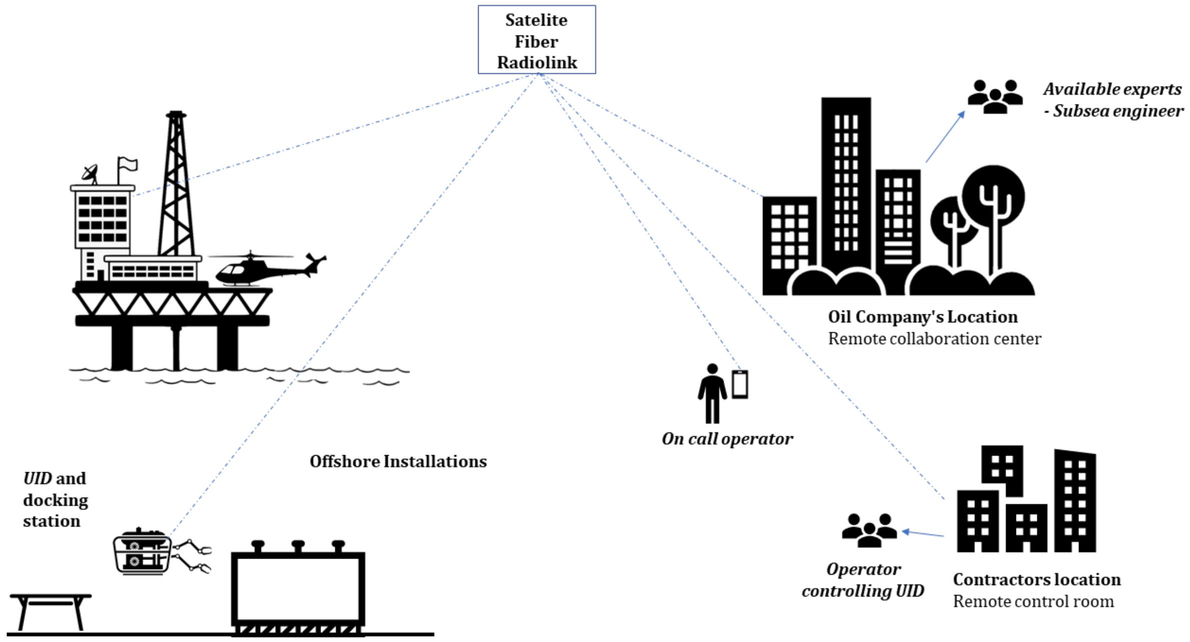

Figure 1.4: Illustration of case scenario

1.3 Objective and Problem Statement

The objective of this thesis is to analyze the chosen case, to assess where the resilience management guidelines could be applied to improve the resilience of the operation. Based on this, a chosen set of capability cards from the DRMG will be adapted for application to the case in question.

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

- *How can the DRMG be adapted and applied to improve resilient management for remote operation in the petroleum industry?*

1.4 Expected Results and Success Criteria

A set of methods will be applied to map out the operation, its actors, functions and activities, and factors related to these. Mapping out important aspects of the operation will paint a picture of the operation in the context of the industry and its external factors. This will constitute a basis to aid the adaption of triggering questions from the DRMG to the case in question.

An interview guide will be developed based on information gathered through the analysis of the operation, integrating triggering questions from the capability cards chosen from the DRMG.

This interview guide will then be applied through interviews with relevant subjects.This will constitute a first attempt at adapting and applying the guidelines to the case in question, as the triggering questions from the CCs will have to be adapted to fit for everyday operation using the data collected through analysis. Finally, based on the finding of the thesis, suggestions will be made as to how the resilience capabilities could be implemented in the management of the operation.

As the thesis is a case study, the results will not be generalizable to all other cases. However, the approach to adapting and applying the DRMGs might be utilized as an approach for other cases. Expected results and success criteria are listed below.

Success criteria :

- Adapt a set of triggering questions
- Test the adapted questions
- Give suggestions on how to implement resilience management

Expected results:

- Method for adaption of triggering questions
- Set of triggering questions adapted to the case, and tested for application

1.5 Scope and Limitations

The thesis will consider the case as described in section 1.2. Case studies are limited in time and space. They allow you to get detailed descriptions and insight into the chosen case, but excludes context that fall outside the scope. When using a case study the results are not generalizable for all other cases.

A chosen set of capability cards from the DRMG will be adapted, and application to the case will be tested through a set of interviews. An evaluation is made based on what capability cards are most relevant, and the maturity of the capability cards. The chosen capability cards are the following:

- Sharing information on roles and responsibilities among different organizations
- Identifying sources of resilience: Learning from what goes well
- Noticing Brittleness

For these capability cards, a list of relevant adapted triggering questions will be developed for application. These will be on a prototype level, and require further testing and revising. There is a time limitation on the thesis, as it is due 07/02-2020.

1.6 Chapter Overview

The chapters in this report are structured as follows:

Chapter 2: Theory
The chapter discusses relevant theory and definitions that build a foundation for the assignment. It will provide the reader with the necessary information to better understand the topics addressed in the literature review. Two main topics are addressed, UID operations in oil and gas, and resilience.

Chapter 3: Method
This chapter will provide the reader with the description and discussion of the chosen methodical approach, how this approach is applied in the study, and criticism of the method. A set of analytical methods where utilized to gather an information basis, before an interview guide was developed using this information in combination with the DRMG.

Chapter 4: Analysis and Results
Here the main results of the thesis will be presented and analyzed. The results present findings from analytical methods that where utilized, as well as the interviews that were performed.

Chapter 5: Discussion
In this chapter the results will be further discussed. The significance of findings will be interpreted and described. The main focus is on divulging how the findings support the use of the DRMG for the case, and how these could be applied and implemented.

Chapter 6: Conclusion
The main conclusion from the work are presented, the implications for the industry, as well as how this could be used in further work.

Appendices
The appendix contains documentation on email communication, the review protocol and search log from the conducted focused literature search, interview information and statement of consent handed out to the interview subjects in advance of the elite interviews, and tables presenting the results of classification, strategies and expectations from the conducted stakeholder analysis, the challenges and opportunities found in the pentagon analysis, and the descriptions from the FRAM analysis conducted. It also include the interview guide containing triggering questions for the interviews conducted. The interview guides are presented both in Norwegian and English.

Chapter 2

Theory Basis

The intention of this chapter is to provide the reader understanding of the basic concepts that form the foundation for the thesis work. Two main categories are addressed;

1. UID operation in oil and gas
2. Resilience

Within the the first category, a set of relevant topics are presented. The chapter starts by introducing remote operation and automation. The transition from remote operation to automated operation is considered, and different automation levels have been presented. Further, remote control rooms and use of unmanned underwater vehicles for inspection and intervention have been addressed. Different topics related to understanding and handling use of systems that are remotely controlled or automated are addressed through sections on Integrated Operations and Human Machine Teaming. Finally, rules and regulations pertaining to use of UIDs have been presented.

As the thesis is focused on improving the resilience in operations in oil and gas, the second category introduce the principles of resilience, Resilience Engineering and resilience management. The safety-I and safety-II perspectives are presented, as well as the differences between applying the rrespective perspectives in operations. Further, the DRMG and the relevant capability cards, which are suggested as a possible guide for implementation of resilience for the case, have been explained.

2.1 Remote Operation, Autonomy and Automation

Remote operation is *to operate a system over a distance* (Lichiardopol, 2007). This involves monitoring and managing processes from a remote location, using different sensors and equipment for collecting and transmitting data for processing (Saeverhagen et al., 2013). Remote operation can be performed for bigger systems, like an oil platform or a ship, parts of a system, or smaller systems, like cars or drones. Remote operation is performed over greater distances, and commonly there is no direct visual contact between the operator and the system being operated.

Applying remote operations can have many benefits for an organization. Reduction in personnel, reduced HSE exposure, reduced risk, reduced costs, improved performance and service quality, improved reliability, and faster decision making and troubleshooting are some of the possible benefits (Saeverhagen et al., 2013). In remote operations, an operator still has full control of the system. However, the system can be automated using automation technology. This gives the system a level of autonomy.

The word autonomy comes from the greek word autonomous, which is a combination of autos and nomos, meaning "self" and "law". Combined, they are understood to mean "having its own laws". The word autonomy is most commonly used to explain independence of countries and people, and describes freedom from external control or influence (Oxford Living Dictionaries, 2017). The word has been adopted to explain technology that makes decisions and performs tasks without human interaction (Grøtli et al., 2015a). When systems have a level of autonomy it is referred to as an autonomous system. The systems are made autonomous by use of automation technology. Automation is defined as *the use of machines and computers that can operate without needing human control* (Cambridge Dictionary, 2019a).

Autonomy is not an all or nothing property of a system. Systems can be autonomous at different levels of autonomy (LOA). The LOA is not necessarily fixed, and can change during an operation (Grøtli et al., 2015a). Grøtli et al. (2015b) have presented 6 levels of autonomy in their report. These LOAs where suggested by the US Navy Office of Naval Research. The different levels can be seen in table 2.1.

Table 2.1: LOA as suggested by US Navy Office of Naval Research (Grøtli et al., 2015b)

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 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 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 a 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 behaviours that it can be understood by its human supervisor and appropriately redirected. The system does not have the capability to self-initiate behaviours that are not within the scope of its current directed tasks.
5	Mixed initiative	Both the human and the system can initiate behaviours based on sensed data. The system can coordinate its behaviour with the human's behaviors both explicitly and implicitly. The human can understand the behaviours of the system in the same way that he understands his own behaviours. 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.

We can separate between autonomous, automatic and remotely operated systems. Autonomous systems have the ability to make decisions. In a fully autonomous system, the operator can only interrupt the system. Automatic systems follow pre programmed commands given by the operator, and can make suggestions if asked by the operator. A remotely controlled system is under full control of an operator, but there is a physical distance between the system and the operator. The main difference between these operation modes, is to what degree the system can make its own decisions, and what degree of control the system operator has. Figure 2.1 shows the correlation between autonomy level and degree of operator control.

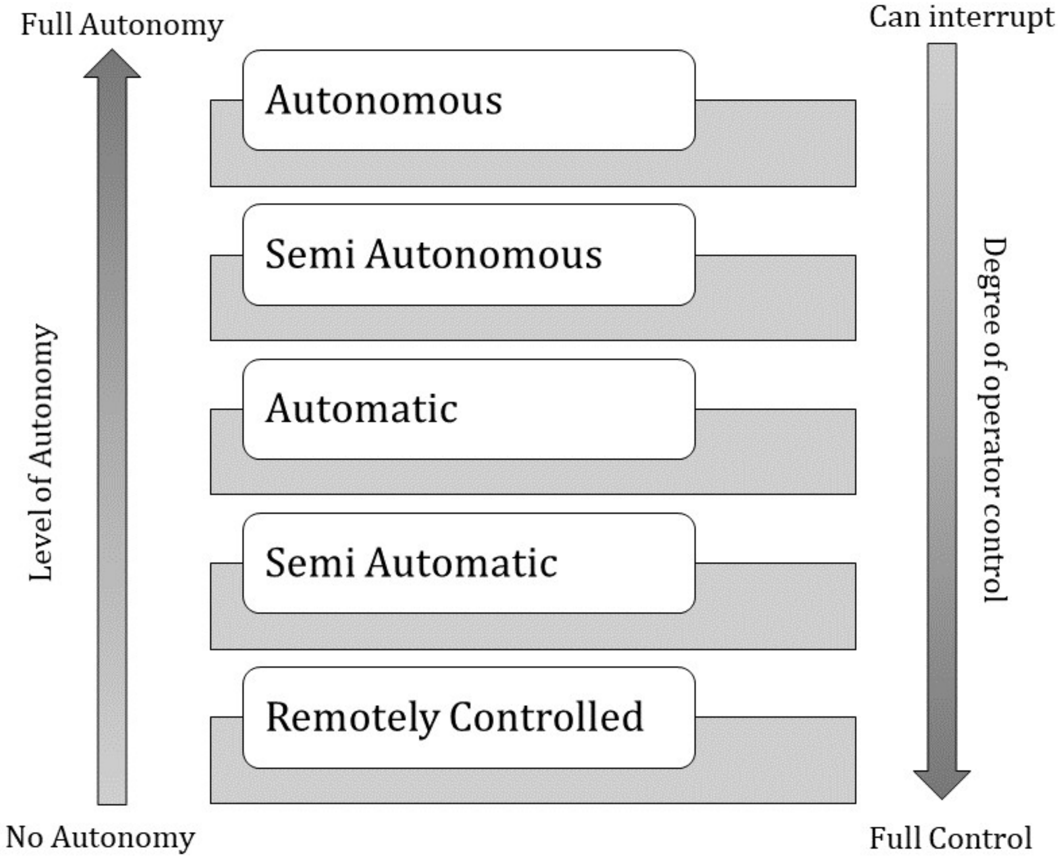

Figure 2.1: Level of Autonomy and degree of operator control

With the advancement of new technology like artificial intelligence (AI), new opportunities present themselves. Machine learning is an approach that utilize AI to learn when performing operations and processes. By applying learning algorithms, data collected during operation can be applied to create a set of rules. This can allow a computer to recognize situations, conditions and events, and know how to, or not to, respond. The use of AI enables automation of systems, as it aids the system in making its own decisions (Internet Society, 2017). Use of automation and remote control is advancing in the oil and gas industry. This is addressed in the following sections.

2.2 Remote Operation and Automation in Oil and Gas

The Oil and gas industry has long had an aspiration to use technology to allow remote operation or automation of their systems and processes. The development is spurred forward by drivers like remoteness, long duration missions and dangerous and challenging areas of operation (Grøtli et al., 2015a). The degree of remote operation has gradually increased since the 1980s. Figure 2.2 shows how remote services and operations have developed in the industry from 1980 to 2015, introducing new technologies and work processes.

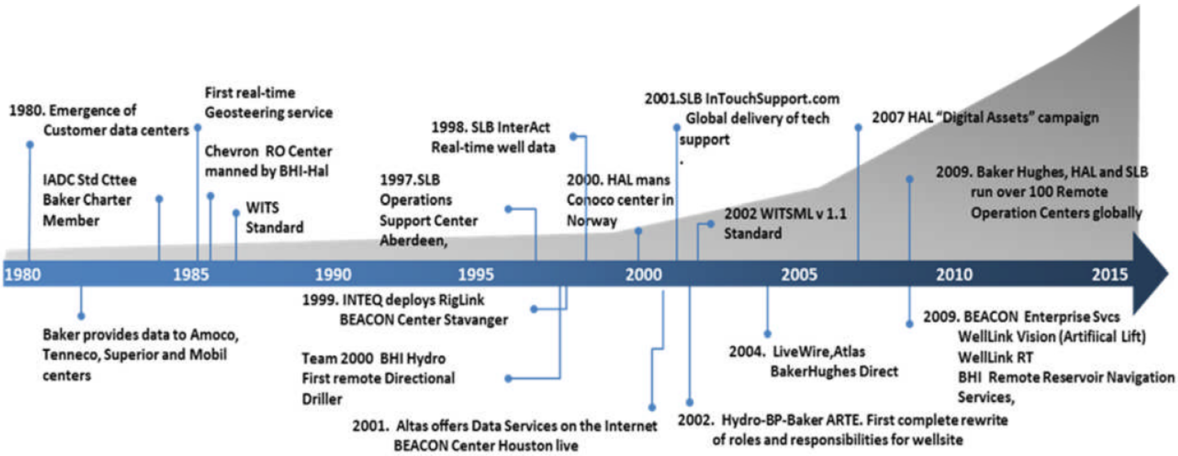

Figure 2.2: Development of remote services and operations (Saeverhagen et al., 2013)

In an interview with Forbes, the managing director for ABB Oil, Gas and Chemicals, Per Erik Holsten, said "The industry is moving towards autonomous operations, and within 10 to 15 years we will have full automation, but for now it's a stepwise process" (Venables, 2018). Full automation in the industry is still some way off. However, certain areas have developed faster such as remote operations and collaboration rooms, manual operations into automated processes, robotic inspections, predictive maintenance, and subsea applications (Venables, 2018). For this thesis the remote operations rooms and the robotic inspection and intervention drones are of particular interest.

2.2.1 Remote Operation Control Room in Oil and Gas

One focus in the Oil and gas industry is to make it possible to remotely control offshore and subsea operations from a control room located onshore. This control room will be part of a bigger ecosystem, as shown in figure 2.3. The ecosystem allows for cooperation within the company, as well as with partners and vendors. The remote control room also makes it possible to create unmanned installations that are remotely operated.

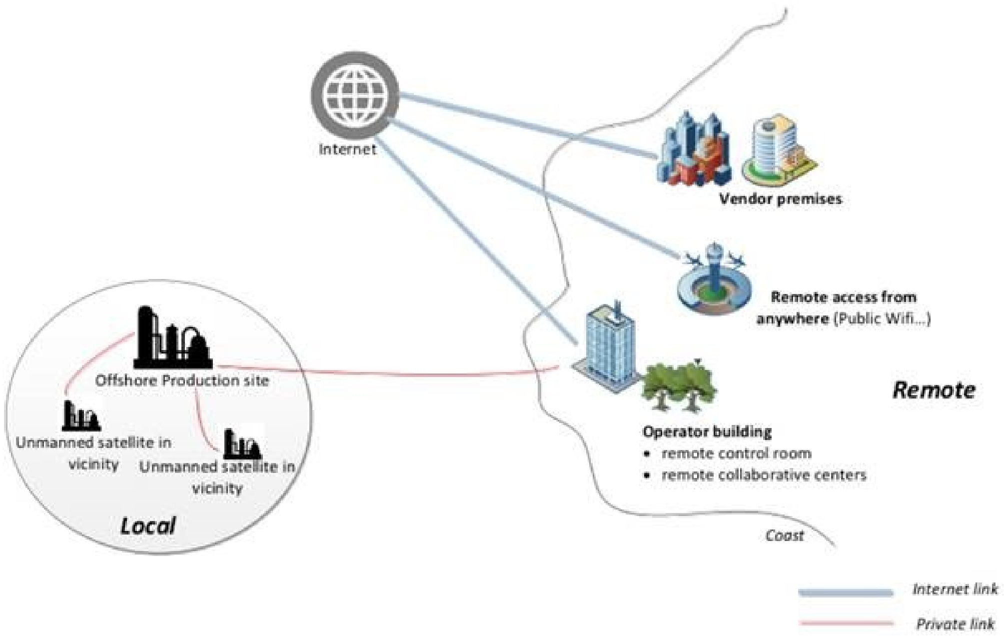

Figure 2.3: The ecosystem for remote operation in Oil and Gas

Remote operation control room is a complex sociotechnical system, that involve multiple aspects. Four main aspects of the system have been suggested by Henderson et al. (2013); technology, people, governance and process. Issues and opportunities related to safety and resilience can be traced back to different aspects of the system. Factors that influence the system within the four main aspects are presented in table 2.2.

Table 2.2: Influencing factors within different aspects of the system

Aspect	Factors that influence the system
Technology	Buildings working environments, facilities, plants, pipelines, sensors, equipment and systems, automation, IT and communication, HMI software/ algorithms and data.
Process	Business processes - workflow, roles and responsibilities, and collaboration
People	Skills, competence, experience, leadership, training and ability to respond, culture etc.
Governance	Organization, positions (decision rights), location of resources, business structure, internal/external sourcing, business model, contracts, agreements, rules, and regulations

2.2.2 Underwater Inspection Drones (UIDs)

Robotic inspection and intervention are very relevant for the oil and gas industry, as they explore deeper and more remote areas of the sea. Traditionally, divers have performed necessary maintenance and inspections. This is costly, and also carries a larger risk, as the waters explores gets deeper. To perform the inspections and interventions, Underwater Inspection Drones(UIDs) can be used. There are different types of UIDs, at different LOAs. In a report on autonomous vehicles, Lloyds register has given the following definition;

Unmanned vehicles are vehicles which are either controlled remotely, or perhaps operate autonomously. Vehicles can also operate semiautonomously: taking some control of aspects of their driving, whilst a human driver retains control of others. Autonomous vehicles are vehicles which can drive themselves without human supervision or input.(Yeomans, 2014).

The two main classes of UIDs are remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). Traditionally, AUVs are mostly used as inspection drones. The AUVs are untethered, and are autonomous or automatic, following pre-programmed or logic-driven mission plans (Christ and Wernli Sr, 2011). They also carry their own power system. AUV often cover larger distances and has longer operating time than ROVs, but the type of operations they perform are different (Antonelli, 2018). The bottom left image in figure 2.4 shows the Remus 6000 AUV by Kongsberg.

ROVs are traditionally remotely controlled through a tether. The ROV also gets its power through the tether. There are different types of ROVs; Working class, Observation class and special use. Observation class vehicles are smaller, often under 70 kg of weight. The purpose of observation ROVs is to gather data through sensors and cameras. The smaller size makes them easier to maneuver in tighter spaces. Many observation ROVs has the possibilities of adding modules of tools and equipment, which enables them to perform tasks beyond the observation (Christ and Wernli Sr, 2011). The right image in figure 2.4 shows an observation ROV from ECA group, with attached modules for manipulator arms.

The working class ROVs have larger frames than the observation ROVs. This enables them to carry multiple manipulator tools, and heavier tools. It is better fit for interventions and tasks on larger subsea structures. They can also be used if parts of the structures have to be moved. The main purpose of these ROVs is to perform various maintenance and intervention tasks subsea. The special use ROVs are vehicles made for special purposes. For example this could be a ROV for cable burial (Christ and Wernli Sr, 2011).

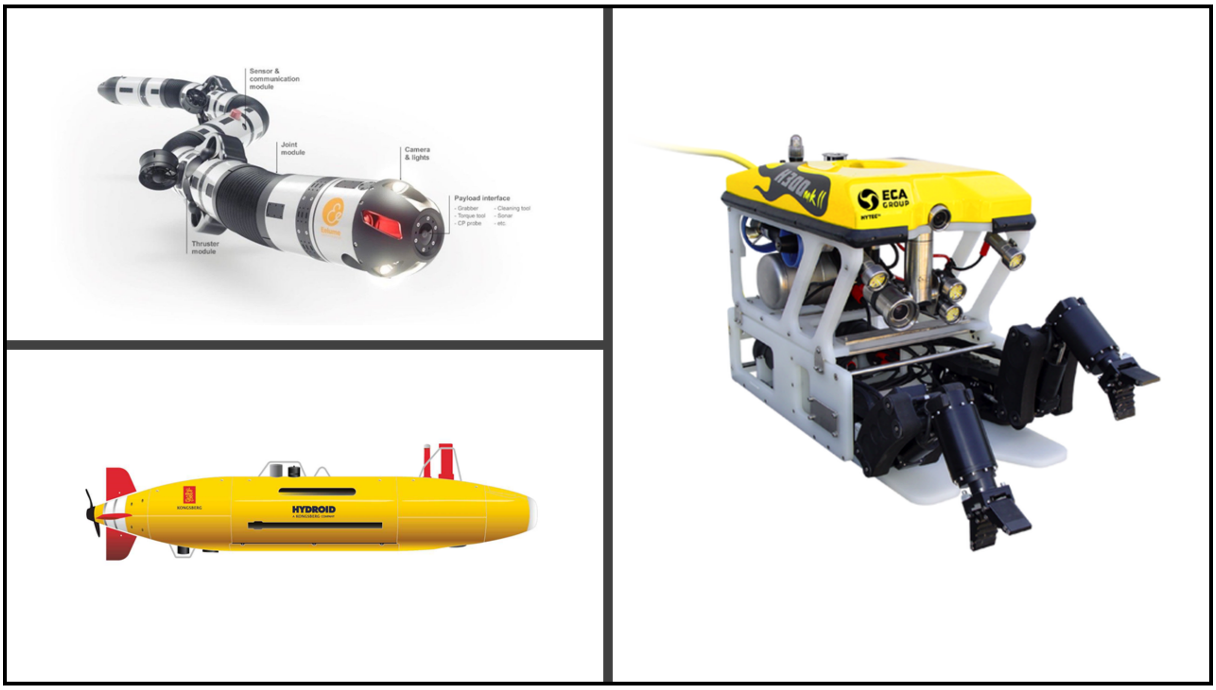

Figure 2.4: Different UIDs (Nautic EXPO, na)(Eelume, na)(ECA Group, na)

New developments and disruptive technologies surface, and makes it possible to improve the subsea inspection and maintenance work. Top left picture in figure 2.4 shows the Eelume vehicle. This is a vehicle that takes the best features of the AUV, observation ROV and working ROV, and combines them into a new concept as can be seen in figure 2.5. The Eelume is designed to live subsea, and operates untethered, unlike the traditional ROVs. The vehicle gets its mission commands and power supply from a subsea docking station.

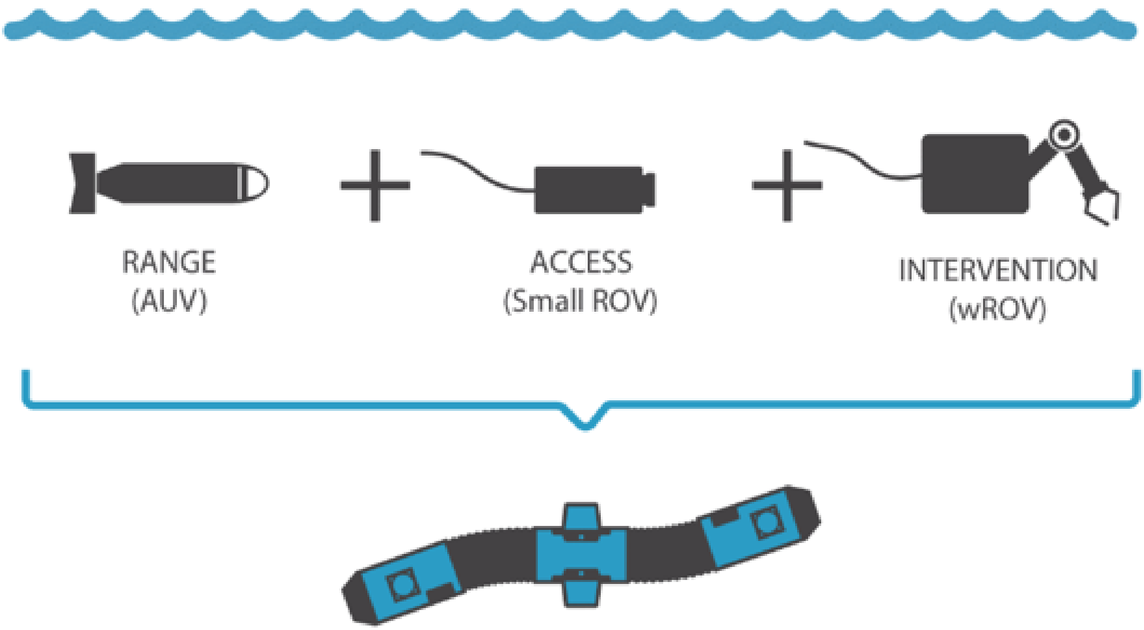

Figure 2.5: Eelume (Eelume, na)

To deal with the increasing use of technology and digitalization, and the shift to remote operation and automation in the industry, Oil and Gas has adapted the integrated operations (IO).

2.3 Integrated Operations (IO)

Integrated Operations is a way to organize work when new work practices and technology is introduced in a company. It promotes cross organizational communication, and features use of real time data, collaborative technologies and cross-dicipline expertice from different organizations across multiple locations (Besnard and Albrechtsen, 2017).

Haavik (2017) suggests the following generic definition of IO; *The integration of people, work processes and technology to increase the quality and speed of decisions and execution, and that this is enabled by the use of ubiquitous real-time data, collaborative techniques and multiple expertise across disciplines, organization and geographical location.*

The main purpose of IO is to improve the safety, both in operations and decision-making, through communication and collaboration (Besnard and Albrechtsen, 2017). IO are thought to make the work *faster, better and safer*. Through the use of technology and good organization, IO can strengthen the effectiveness, safety and competitiveness in the industry. IO contributes to increasing value creation, and improving HSE.

IO facilitates the use of technology in work processes. The IO is an important concept in the ongoing change process in the industry (Haavik, 2017). The IO practices are therefor important in the new development toward more remote control and automation in operations and processes.

2.4 Human Machine Teaming

Human machine teaming (HMT) has been a popular field of research as technology and systems of varying level of autonomy are developing rapidly. The research focuses on the integration of humans and complex systems. This requires research into human factors and software engineering, as well as system design.

If human operators are to interact with the system, they have to understand what the system is doing and be able to communicate with the system. A common cognitive- and knowledge framework are important for the human-machine interaction. Successful HMT will exploit the strengths of both the human and the machine. If they are to intervene, they have to understand when and why. HMT is about communication and collaboration between the human operator and the machine. There are a set of factors that have to be in place for this interaction to be fluid. There are system, environment and human factors to consider in HMT. (Chen and Barnes, 2014)

McDermott et al. (2018) have developed guidelines for HMT, where they point out 10 factors to support HMT. The factors can be seen in figure 2.6. The guide was created to help system developers design for autonomy and automation that is centered on adaption to the human operator. The guidelines set requirements to the design of the systems, as well as the operators understanding of the system.

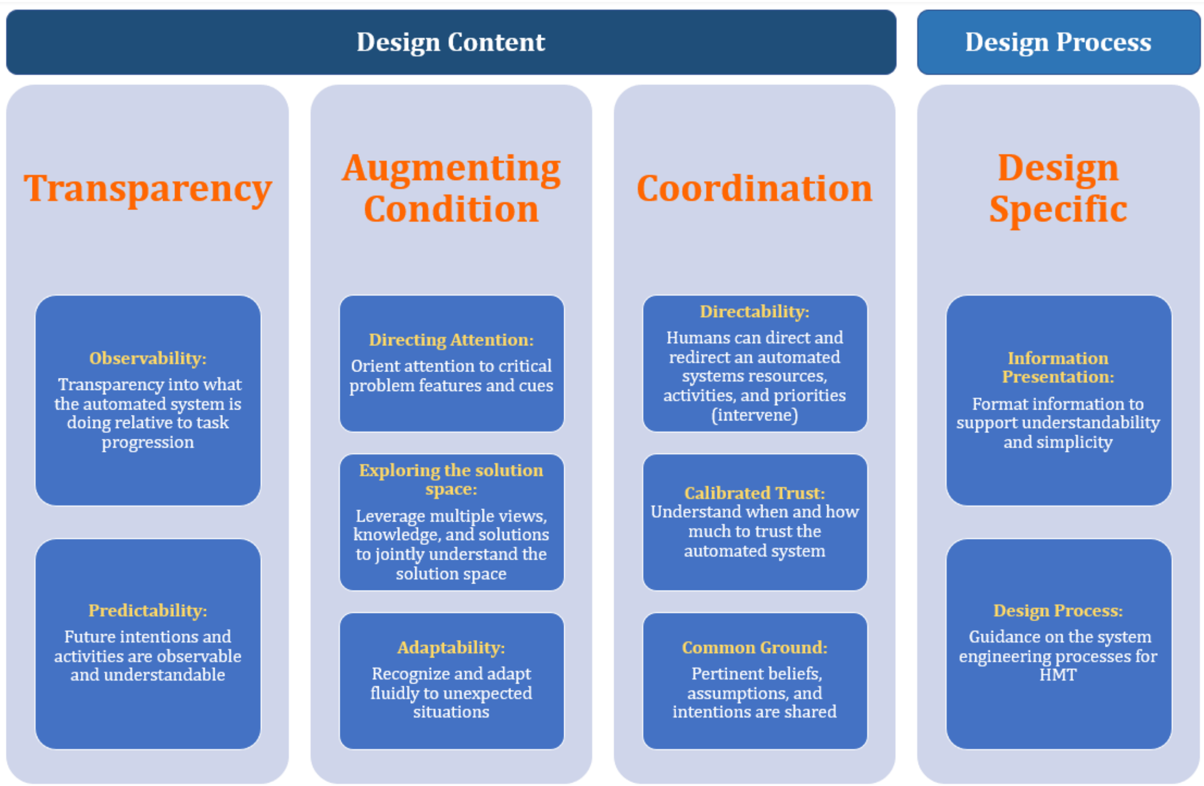

Figure 2.6: Focus areas to support HMT. Based on figure by McDermott et al. (2018)

Human machine teaming is an important consideration in autonomous and remotely operated systems, and should be incorporated in the development and management of the operation. In addition to managing technological, human and organizational factors in the operation, external influences must also be considered. The laws and regulation pertaining to the operation must be adhered to. Relevant existing regulations are presented in the following section.

2.5 Laws and Regulations

Operations on the Norwegian continental shelf has to be performed in accordance to regulations set by the Petroleum Safety Authority (PSA). They are the supervisory and administrative agency who has regulatory responsibility for safety, working environment, emergency preparedness and security in the petroleum sector. They set the regulations for offshore activity as well as onshore petroleum plants, and follow up the activities in the sector (Petroleum Safety Authority, 2019). For land-based offices in the sector, and other sectors, it is the Norwegian Labour Inspection Authority that sets the regulations for working environment and safety, and follow up (Norwegian Labour Inspection Authority, 2019). Figure 2.7 shows how authority is divided offshore and onshore. As the operation of the UIDs is performed remotely, the control room is located onshore. When the control room is located offshore it falls under the jurisdiction of the PSA, but when it is located onshore who has the authority and what regulations apply is a more complicated case.

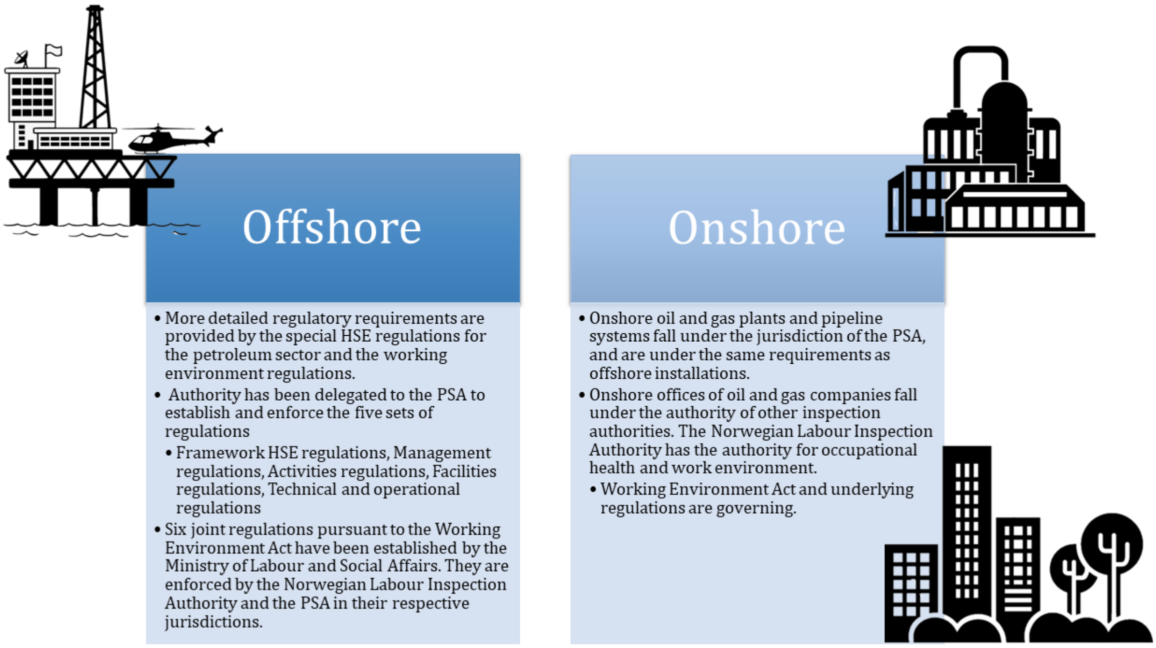

Figure 2.7: Acts, regulations and authority offshore and onshore

The Petroleum Safety Authority in Norway was contacted to clarify what regulations apply for the case of an onshore control room. The full reply from the PSA can be seen in appendix A. The email clarifies that for the control room onshore, the PSA will not have authority to enforce the working environment act. This authority falls to the Norwegian Labour Inspection Authority. However, the parts of the onshore business that is necessary for acceptable and safe operation offshore will fall under the Petroleum act. The requirements for safety and acceptable operation will be regulated by the Petroleum act, and the PSA is the enforcing authority. They can perform inspections to ensure that safety critical operations live up to the given requirements. The PSA can also enforce relevant requirements in the HSE regulations that are motioned in the Petroleum act. In some cases there will be overlap between safety requirements in the petroleum act and the working environment act. In these cases it has to be evaluated if the offshore acts and regulations apply to onshore functions. There is ongoing work to create good cooperation between the Norwegian Labour Inspection Authority and the Petroleum Safety Authority regarding inspections of onshore control rooms.

In addition to the regulations of safety and work environment, the drones themselves must adhere to standards and regulations. For aerial drones regulations have been developed. This is not the case for UIDs. In maritime regulations there are definitions of *ships* and *naval artifact*, and the drones can not easily be fit into either of these categories. The ship definition requires the drone to navigate by sea and carry persons or other objects. The naval artifacts are required to be located in a fixed point. Although the drones do not fit into the regulations, classification companies have used adaptions of these rules to cover the underwater vehicles, and provide classification standards for the drones (Garrigues, 2015).

DNV GL have developed their own rules for classification and construction of unmanned submersibles (ROV, AUV) and underwater working machines. The rules covers construction of all the systems of the vehicles, as well as their operating and monitoring systems. They cover both tethered and un-tethered vehicles (DNV GL, 2009). The standard does refer to vehicles that are submersed from the surface. Therefore, the rules does not cover equipment like the docking station, but rather systems above water like launch systems, stowage and supply system on a ship or platform. The rules ensures that the vehicles are built to safely perform their operation from a technical and mechanical standpoint (DNV GL, 2009).

The Norwegian petroleum industry have developed a set of industry standards, NORSOK. The standards are meant to help the industry achieve sufficient safety, value adding and cost effectiveness in their developments and operations. NORSOK standard U-102 addresses remotely operated vehicle (ROV) services, and was developed to standardize ROV operations in the industry. The standards also cover similar operations applying autonomous underwater vehicles (AUVs), remotely operated tool (ROT), remotely operated towed vehicle (ROTV) and dredging machines operating with similar technology to ROVs (Standard, 2016). The standard defines requirements for personnel, equipment and systems related to ROV operations. Personnel must meet qualification requirements, and the systems and equipment technical requirements as well as interface requirements. There are also a set of administrational requirements. (Standard, 2016)

2.6 Resilience

The following sections addresses to relevant principles and theories related to resilience. Resilience is in the Cambridge Dictionary (2019b) defined as *the ability to succeed, or restore to previous condition, after unwanted events or crisis*. The term has been used for a long time, and in a broad range of fields. Resilience can today be divided into four categories. Modulus resilience is used to describe a materials ability to withstand harsh conditions. Psychological resilience describes stress resistance and robustness in humans and businesses. Ecological resilience is a measurement for ecosystems ability to consume, adjust and survive change. Lastly, engineering resilience refers to a systems ability to withstand and return to initial state after disturbances (Hollnagel, 2016c).

Resilience is believed to have the potential to address the increasing complexity in the global risk landscape. This potential has led to an increasing popularity of the term over the last years. Herrera et al. (2018) points to an exponential increase of scientific articles focused on resilience in critical infrastructures over the years, as can be seen in figure 2.8. Further Herrera et al. (2018) points out that the popularity have led to different understandings of resilience, and over 300 definitions of the term. To fully utilize the potential of resilience, clarity on how to operationalize resilience is needed (Herrera et al., 2018).

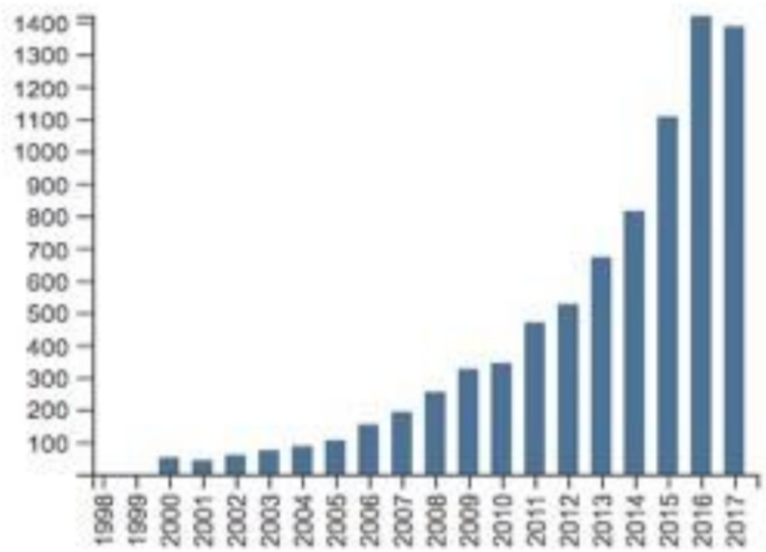

Figure 2.8: Number of scientific articles focused on resilience in critical infrastructures (Herrera et al., 2018)

2.6.1 Resilience Engineering (RE)

Resilience Engineering was developed as an extension to traditional safety in the beginning of the millennium. The scope was to address the new safety challenges created by today's risk picture, recognized by increased complexity and tightly coupled interactions (Hollnagel et al., 2010). Resilience Engineering should be understood as the capability to perform in a resilient way, not as a property. The view on Resilience Engineering has developed over time, from a the reactive, to a more proactive safety view. This development has led to evolving definitions on the term. Hollnagel (2016c) defines resilience engineering as; *A system is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions*. He also points out that this definition probably isn't final, as the scope of Resilience Engineering should free itself from its initial frame, focused on conventional safety thinking.

There are four cornerstones of resilience, each representing essential abilities for resilient performance. These can be seen in figure 2.9 (Hollnagel, 2011).

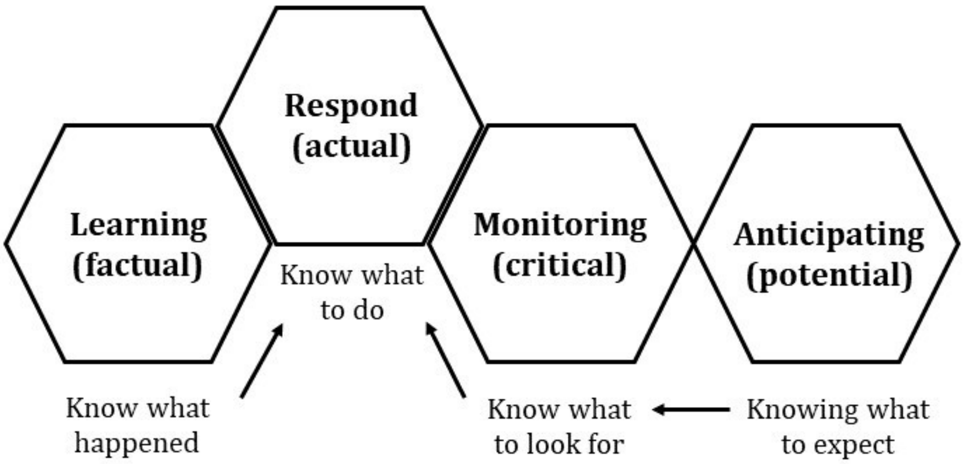

Figure 2.9: The four cornerstones of resilience, figure based on Hollnagel (2011)

- The potential to **respond**: The ability to respond to expected and unexpected, situations, changes, opportunities and disturbances. This can be achieved by adjusting to normal functioning, or by implementation of a prepared response. (Hollnagel, 2016b).
- The potential to **monitor**: The ability to look for, or monitor external and internal factors that are affecting, or have the potential to affect performance. (Hollnagel, 2016b).
- The potential to **learn**: The ability to learn the right lessons from the right experiences, both failure and success. (Hollnagel, 2016b).
- The potential to **anticipate**: The ability to anticipate further developments and consequences, both challenges and potential opportunities to exploit (Hollnagel, 2016b).

In 2015 Woods (2015) performed a literature study on resilient capabilities within different sectors, were he discovered four mutual concepts as presented in figure 2.10:

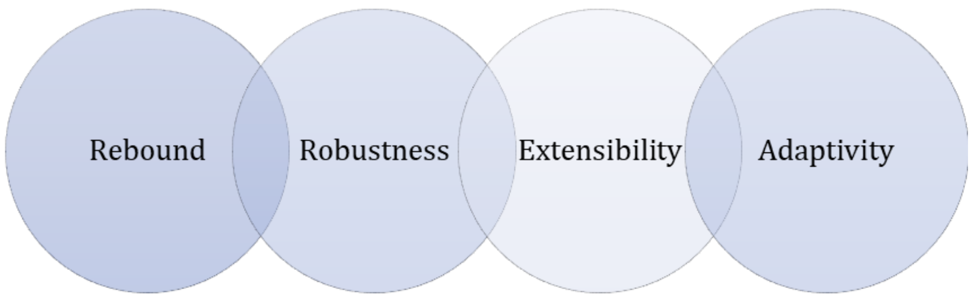

Figure 2.10: Four resilient concepts

- **Rebound:** the systems ability to rebound and restore from crisis and disturbance (Woods, 2015).
- **Robustness:** points to the systems ability to handle challenges, stressors and increased complexity (Woods, 2015).

- **Extensibility (Graceful extensibility):** points to the ability to stretch the systems performance, when confronting unexpected events that challenge the existing boundaries (Woods, 2015).

- **Adaptivity (Substained adaptivity):** the ability to adjust to upcoming unexpected events due to evolving conditions (Woods, 2015).

In resilient engineering graceful extensibility and sustain adaptability is addressed (Woods, 2018).

2.6.2 Resilience Management

The four resilient cornerstones are highly interconnected and coupled, and should not be viewed as independent, but as connected and interrelated. When managing for resilience, the cornerstones must therefor be viewed as one. The cornerstones can therefor be used to gain an understanding of the full picture of the organization of the operation (Hollnagel, 2016b).

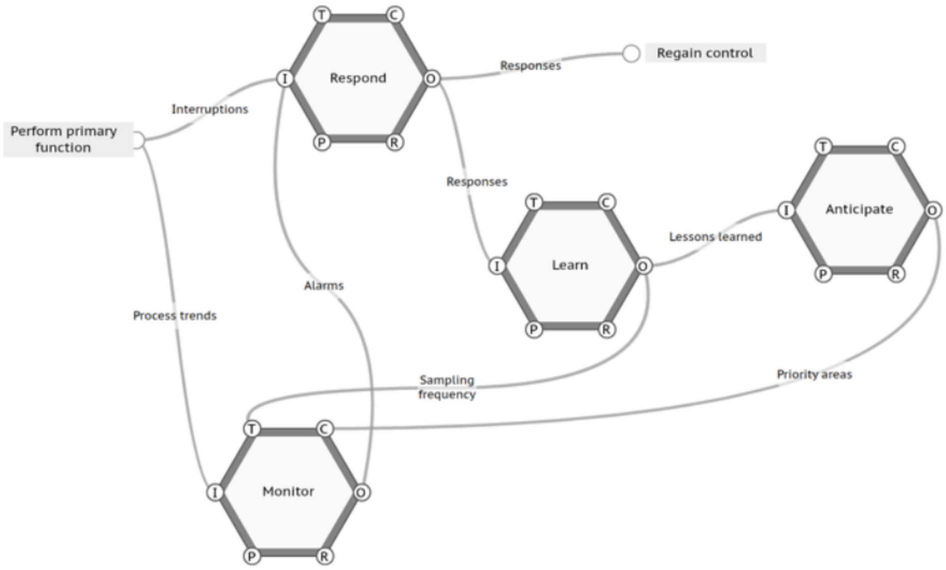

Figure 2.11: The four resilient cornerstones and their interrelations (Hollnagel, 2016b)

Figure 2.11 illustrate how the four cornerstones are interrelated, where normal performance variability in one, might have effects on the others. High risk industry, such as the petroleum industry, is recognized for the use of extensive layers of protective and reactive barriers and safety systems. The industry highlights the use of defense in depth as a contributing factor to the low probability of major accidents (Hauge and Øien, 2016). A consequence of the extensive barrier layers, is that it creates increased complexity in the system. The complexity is also expected to continually increase in the future. Traditional safety thinking does not address these interactions and couplings (Hollnagel et al., 2010). Due to the degree of interrelations between the cornerstone's, there will also always be an element of trade-off when managing the elements.

In general the four cornerstones of resilience can be used to distinguish between four categories of organizations and systems:

Table 2.3: The four categories of resilient systems and organizations

Type of system/organization	Ability	Description
Systems of the First Kind	Monitor Respond	Systems or organizations with the ability to respond appropriately to both expected and unexpected events, and, therefor sustain operation (Hollnagel, 2016c).
Systems of the Second Kind	Monitor Respond Learn	Systems of the second kind have the ability to respond to events, to learn from them, and adjust based on the experience (Hollnagel, 2016c).
Systems of the Third Kind	Monitor Respond Learn Anticipate	Systems/organizations of the third kind can be recognized by the ability to predict for future events and prepare for them. This ability to anticipate is achived by the use of leading indicators, to analyse future developments. These systems meet the criterias for resilience. (Hollnagel, 2016c)
Systems of the Fourth Kind	Monitor Respond Learn Anticipate	Systems of the forth kind meet all the qualifications for resilient systems. But in these systems the ability to anticipate also include the system itself, how the surroundings will respond to changes, and how this response can affect the system (Hollnagel, 2016c). An understanding necessary when handling todays complex systems.

2.7 Traditional Safety versus Resilience

Traditional safety management has a bimodal safety view, focused on reducing the number of events that go wrong, by identification of causes and determination of risk. But the changing risk picture of today's society, recognized by increased complexity and interdependence, has led to a gradually shifting and increasing focus on the use of diverse perspectives to enhance safety.

2.7.1 Safety I and Safety II

Resilience Engineering initiated the development of two different perspectives on safety, referred to as safety-I and safety-II (Hollnagel et al., 2015). The two perspectives have a different focus areas, as presented in figure 2.12.

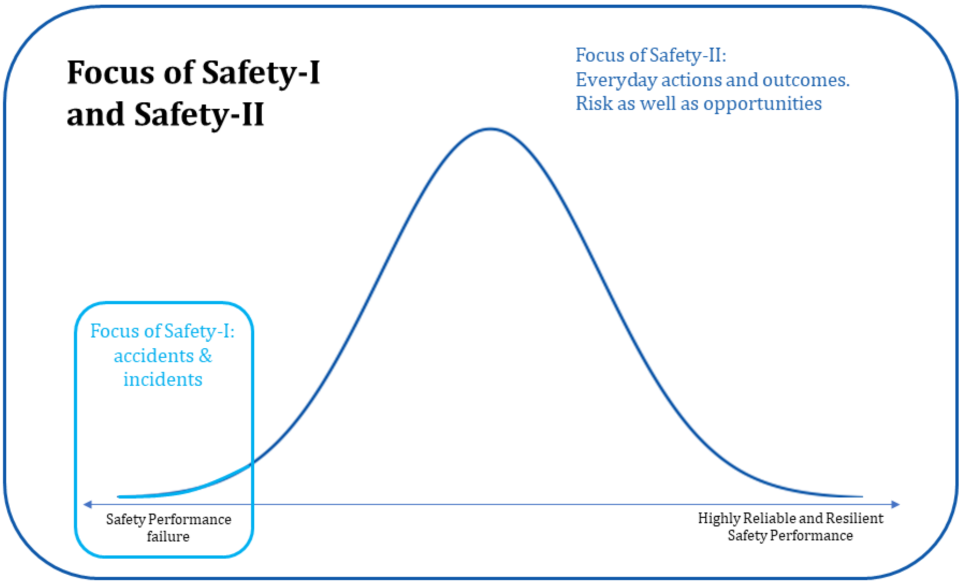

Figure 2.12: Focus areas of safety-I and safety-II,based on figure by Hollnagel et al. (2015)

The traditional safety perspective, safety-I, focuses on what can go wrong and identifying the causes of events. The new perspective, initiated by the Resilience Engineering thinking, introduces a way of thinking where not only cases where things go wrong are considered, but also cases where things go right. It states that things that go wrong and right, happen in the same way. Safety-II therefor focuses on variability in everyday operations, and developing an understanding of it. The difference between work as imagined (WAI) and work as done (WAD), is considered (Hollnagel, 2013).

While safety management in a safety-I perspective is reactive, the safety-II perspective adopts a proactive approach. The aim of the perspective is for everyday work to fulfill its intended purpose. As the perspective assumes that all events happen in the same way, regardless of outcome, the causes for what goes right and wrong are the same. The perspective strives towards ensuring that things go right, and as such reduce the number of events that go wrong. A proactive approach requires anticipating with acceptable certainty what can occur, so that the system or organization can be prepared to respond to expected and unexpected events. (Hollnagel, 2013)

2.7.2 Resilience Applied to Operations

Safety management has gone through many phases the last 100 years. From a focus on human factors, to an increasing focus on the effects of the rapidly evolving technological systems, before the focus shifted to organizational factors and root causes. Todays safety management tries to combine these when considering safety. Due to an increase in dependencies and interconnections in systems, as well as an increasing degree of complexity, established safety methods and tools fail to explain, predict and prevent new accidents. The different risk factors cannot simply be added together, but the effect they have on each other has to be considered (Hollnagel et al., 2010).

Resilience Engineering states that variabilities in performance cannot be avoided, and could in some situations be useful. As complexity and interdependencies across systems and organizations increase, it can be concluded that procedures and plans will be incomplete, as they cannot cover all possible variabilities. Strictly following the procedures could therefore be considered unsafe or inefficient in some occasions. Increasing the resilience capabilities of operations would improve their capability to adapt to such variabilities, and is therefore a good way for operations to improve its safety performance. (Hollnagel et al., 2010)

Resilience management would increase the foundation of data that could be applied to learn and improve safety of the operation. When applying Resilience Engineering thinking, the whole range of outcomes, both positive and negative as presented in figure 2.13, are considered. In the traditional safety-I perspective, the focus is on the negative outcomes, and what can be learned from these to try and prevent them from happening again. But as previously stated, the same operating conditions that lead to success one time, could lead to failure another. Utilizing the positive outcomes to learn from what goes well, provides a big increase in data to apply. The frequency of successful operation is much larger than that of operations that fail and have serious consequences (Hollnagel, 2011).

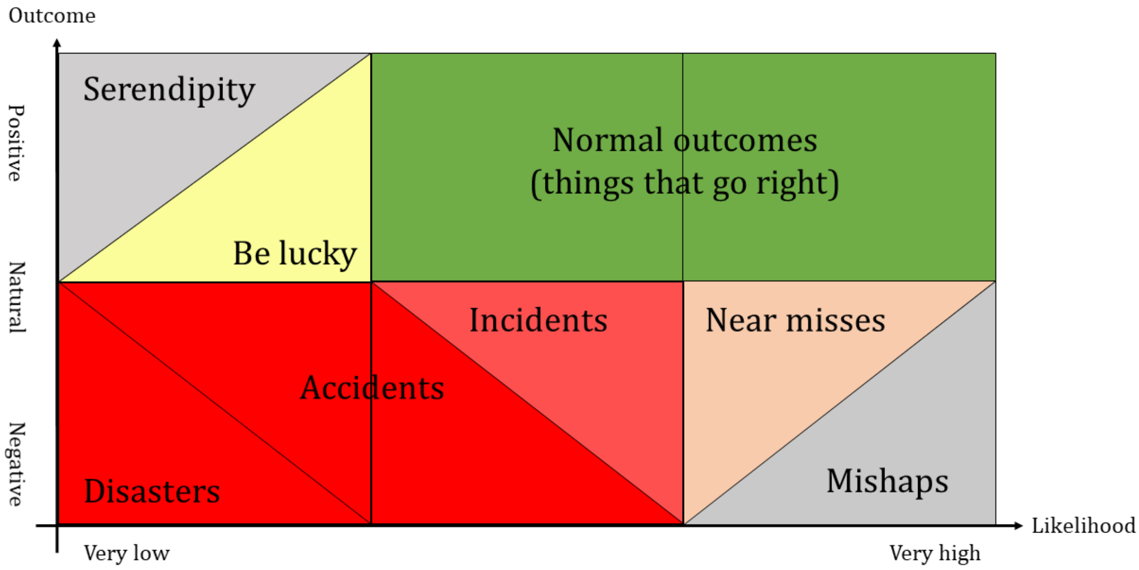

Figure 2.13: Based on figure by Hollnagel et al. (2010)

To deal with the new challenges of operations and systems, resilience engineering apply a systematic approach for evaluating the resilience. Possible methods for application are Functional resonance analysis method (FRAM) and Resilience analysis grid (RAG). FRAM identifies variabilities in an operation by applying a systemic view, and considering functional resonance between variabilities of functions. RAG is a simple method to consider the resilience performance of an organization or operation. Adopting a Resilience Engineering view does not require that existing practices are discarded completely. However, it does mean that existing practices are considered in a different way, which again could change how they are applied, as well as how their results are interpreted (Hollnagel et al., 2010).

2.8 The DARWIN Resilience Guidelines (DRMG)

The DARWIN Resilience Management Guidelines (DRMG) consist of a collection of generic guiding principles, created to help or assist organizations in the process of developing, assessing or enhance its existing procedures, regulations and practices based on resilience management concepts. The guidelines are not intended to replace the existing procedures, regulations and practices, but act as a complementary aid to indicate criteria to increase the organizations resilience. The aim of the DRMG is to assist the organizations handling critical infrastructures through a critical evaluation of their existing crisis management activities, such as management of training, resources and procedures. Due to their nature, the DRMG are mainly directed towards the decision makers, managers and policy makers in organizations, responsible for the organizations crisis management activities.

The DRMG addresses a total of thirteen resilience management capabilities, divided into six main themes. Each capability is represented by a capability card (CC). The overall picture of the resilience management capabilities addressed in the guidelines, is presented in the DRMG map in figure 2.14. The map shows the CCs, the topics within each CC, and the relations between them.

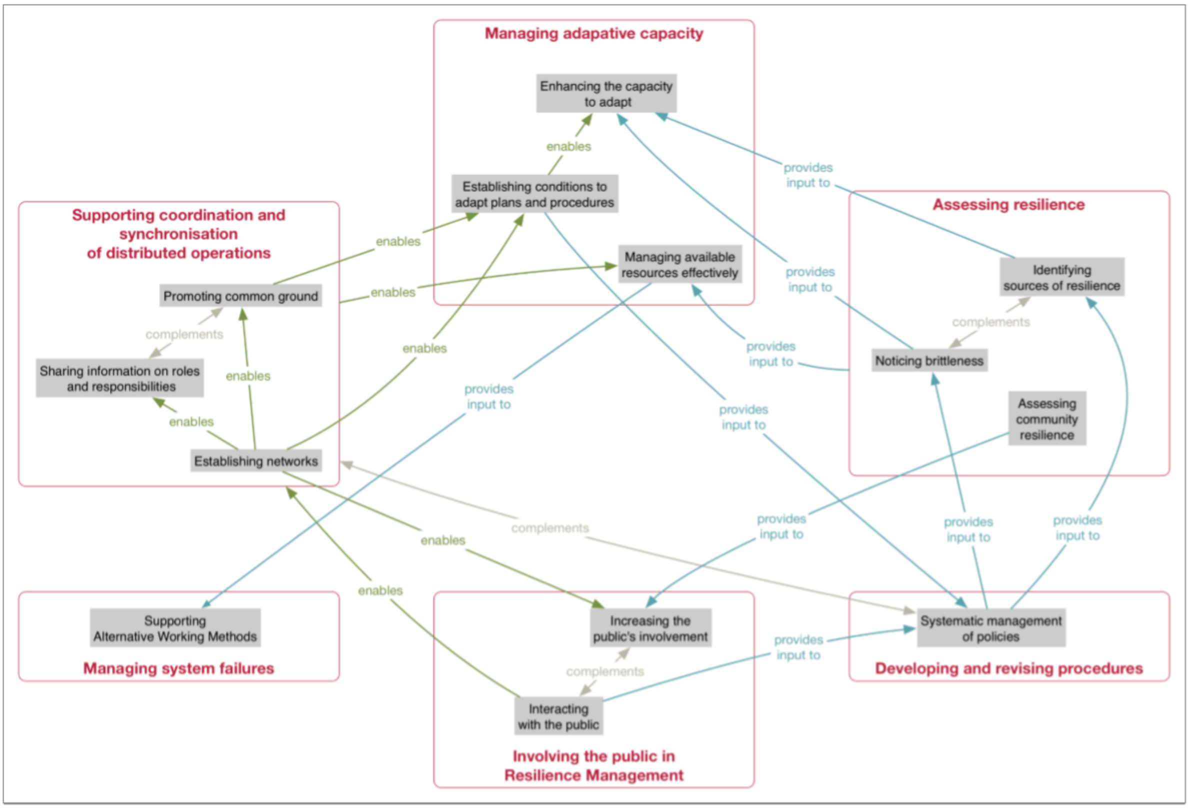

Figure 2.14: DRMG Map (Herrera et al., 2019))

The DRMG does not consist of step-by-step prescriptions, but need to be interpreted and adapted to the specific context, goals and the organizational characteristics. Table 2.4 shows the same themes and topics as the DRMG map, with longer more descriptive titles for the topics. The capability cards are further described in the following sections.

Table 2.4: The DRMG Themes and Topics. Retrieved from (Herrera et al., 2019)

DRMG Themes	DRMG Topics
Supporting coordination and synchronization of distributed operations	• Promoting common ground for cross-organizational collaboration in crisis management • Establishing networks for promoting inter-organizational collaboration in the management of crises • Ensure that the actors involved in resilience management have a clear understanding of roles and responsibilities in own and other organizations involved in the management of the crisis
Managing adaptive capacity	• Enhancing the capacity to adapt to both expected and unexpected events • Establishing conditions for adapting plans and procedures during crises and other events that challenge normal plans and procedures • Managing available resources effectively to handle changing demands
Assessing resilience	• Assessing community resilience to understand and develop its capacity to manage crises • Identifying sources of resilience: learning from what goes well • Noticing Brittleness
Developing and revising procedures and checklists	• Systematic management of policies involving policy-makers and operational personnel for dealing with emergencies and disruptions
Involving the public in Resilience Management	• Communication strategies for interacting with the public • Increasing the public's involvement in resilience management
Managing system failures	• Supporting development and maintenance of alternative working methods

2.8.1 Capability Cards (CC)

The capability cards constitute the building blocks of the DRMG. The cards consists of a set of interventions that could help develop and enhance an organizations resilience management capabilities. Each card addresses a specific management capability. The CCs were created based on knowledge gathered through interviews and literature reviews. As is illustrated in the DRMG map in figure 2.14, the CCs are not independent of each other, but relate and interact with each other (DARWIN, 2018c).

The CCs consist of information that aid in understanding and implementation of proposed interventions (DARWIN, 2018b). The following elements are provided within the CCs;

1. **Background information**: Here the objectives and logic behind the capabilities are explained, as well as expected benefits, challenges and actors (DARWIN, 2018b).

2. **Descriptions of interventions**: As the guidelines were originally made for resilience management in crisis management, this part is organized into three phases of crisis management, namely before, during and after a crisis. The description includes a set of *triggering questions* that addresses crucial issues that should be addressed. These should help form a resilience oriented perspective. The implementation of interventions are de-

scribed in more detail, and the implementations maturity has been estimated, and costs of implementation is discussed (DARWIN, 2018b).

3. **Categorization information**: Here the CCs are associated with other themes or categories, resilience abilities, functions and types of actors. Relation to other CCs is also provided when this is relevant (DARWIN, 2018b).

As stated in section 1.5, two themes and three related CCs have been chosen as main focus in this thesis. These are part of more mature cards in the guidelines. They are;

1. Supporting coordination and synchronization of distributed operations
   (a) Sharing information on roles and responsibilities among different organizations
2. Assessing Resilience
   (a) Identifying Sources of Resilience: Learning From What Goes Well
   (b) Noticing brittleness

2.8.2 Sharing Information on Roles and Responsibilities Among Different Organizations

This capability card highlights the importance of understanding the roles and responsibility of anyone involved in the management of an event. Everyone should have knowledge of roles and responsibilities internally, as well as externally (DARWIN, 2018b). The following aspect should be known;

1. Who should be contacted
2. Maintain knowledge of the relevant management roles, both the generic and situation specific
3. Knowledge of the different roles high level responsibilities, to ensure accurate expectation under the interaction

To ensure this capability, a network of collaborating organizations must exist (DARWIN, 2018b). The operation considered in this thesis involve various stakeholders, both at different levels internal in the organization, and external parties. Particularly the relation between the oil company and the contractor who will perform the operation should be considered. The roles and responsibilities of involved stakeholders need to be clarified to ensure that this management capability is sufficient.

Improving this capability is expected to have the benefit of an improved ability to act. This would lead to a more effective mitigation of effect of events, and a improved ability to bounce forward after events. (DARWIN, 2018b)

2.8.3 Identifying Sources of Resilience: Learning From What Goes Well

As previously mentioned, one of the aspirations of Resilience Engineering is to learn from everyday performance and successful operations, rather than failure and lessons learned. As such, this capability deals with identifying sources of resilience to investigate how expected and unexpected events are handled successfully. This could be strategies, processes or tools that aid the organization in performing and adapting to deliver the required result, in the face of different variabilities and complexity in the operation. It can be identified by looking at WAD (work as done) in everyday operations and unexpected situations, to identify what goes well and learn from it (DARWIN, 2018b).

The process of identifying sources of resilience consist of the following steps;

1. **Construction of the skills needed for understanding and identification of sources of resilience**: First, the foundation of skills necessary to develop an understanding of, and an ability to identify, the sources of resilience in the operation needs to be built (DARWIN, 2018b)

2. **Selection of method for identification of the possible sources of resilience**: This should be performed with the involvement of different actors on different levels in the organization, to get a range of perspectives. A combination of individual interviews and workshop based techniques can be applied. Time constrains and availability of resources has to be considered. (DARWIN, 2018b)

3. **Triggering questions**: The method should be planned considering use of triggering questions in the guidelines to be used as a guide. The triggering questions can be used to define and describe the everyday operations, or to look at past events to identify skills, strategies and procedures that aided the success of the operation. (DARWIN, 2018b)

4. **Revision of internal guidelines**: The outcome can be applied to revise internal guidelines and training, or to create new guidelines for the specific purpose (DARWIN, 2018b).

Improving this capability is expected to give a better understanding of everyday operation with the focus on crucial functions. The understanding can be applied to improve the organization's resilience capabilities. This ensures that everyday operations go well as often as possible (DARWIN, 2018b).

2.8.4 Noticing Brittleness

The aim of the proposed interventions for this CC is to identify sources of brittleness. This would allow the organization to invest in corrections. Brittleness is something organizations experience with occurrence of situations with goal conflicts, trade-offs, and competition for resources with need for priorities. It can also be an organizations struggle to deal with interdependencies between different parts, that can cause propogating consequences, or insufficient capacity of additional resources. (DARWIN, 2018b)

Noticing brittleness involves observing variabilities in operation, and comparing WAI (work as intended) with WAD (work as done), to reveal if the system is operating with higher risk than anticipated. Brittleness will present itself if the organization does not learn from past events like near misses and accidents (DARWIN, 2018b).

The following steps are necessary to notice brittleness;

1. **Engage personnel**: Personnel of all levels in the organization should be engaged in the work of understanding and noticing brittleness (DARWIN, 2018b).

2. **Create the conditions**: Conditions to expose and discuss what go well or not during an event should be facilitated for personnel on all levels in the organization (DARWIN, 2018b).

3. **Implement recommended activities**: The activities should be regularly implemented to aid the personnel's ability to notice and discuss brittleness (DARWIN, 2018b).

4. **Rely on external experts**: If resilience or safety managers that are familiar with the concepts of resilience are not available in the organization, external experts should be sought out (DARWIN, 2018b).

5. **Select methods for the identification of possible sources of brittleness**: Involve roles and actors at different levels in the organization in selection of methods, to ensure a range of perspectives. A combination of individual interviews and workshop-based techniques can be applied. Time constraints and available resources has to be considered (DARWIN, 2018b).

6. **Triggering questions**: Should be included when planning methods to be used as guide for the analysis (DARWIN, 2018b).

7. **Revision of internal guidelines**: The outcome can be applied to revise internal guidelines or create new guidelines for the specific purpose. (DARWIN, 2018b)

Improving this capability is expected to allow the organization to address its sources to brittleness, and the underlying factors. In this way they can avoid events that results in possible harm or damage (DARWIN, 2018b).

Chapter 3

Method

As previously stated, the objective of this thesis is to apply a chosen set of capability cards from the DRMG, to the case in question, and apply these to consider if they can induce reflections and evaluation on the resilience management of the operation. The following problem statement has been proposed;

- *How can the DRMG guidelines be adapted and applied to improve resilient management for remote operation in the petroleum industry?*

To address the problem statement and achieve the objective, a mix of analytical methods will be applied to create an understanding of the operation in context of the industry and its external factors. Further the findings from the various methods will be compiled, and discussed in the light of the DRMG. The picture of the operation that was created in the first step, will further be used to develop interview guides based on triggering questions from the chosen capability cards in the DRMG. This represents an initial attempt at adapting the guidelines to the case in questions. The interview guide will be applied in interviews with chosen personnel from the oil company. This will reveal whether the adapted questions can be applied to improve resilience in the case operation. Figure 3.1 shows the main steps of the methodical approach.

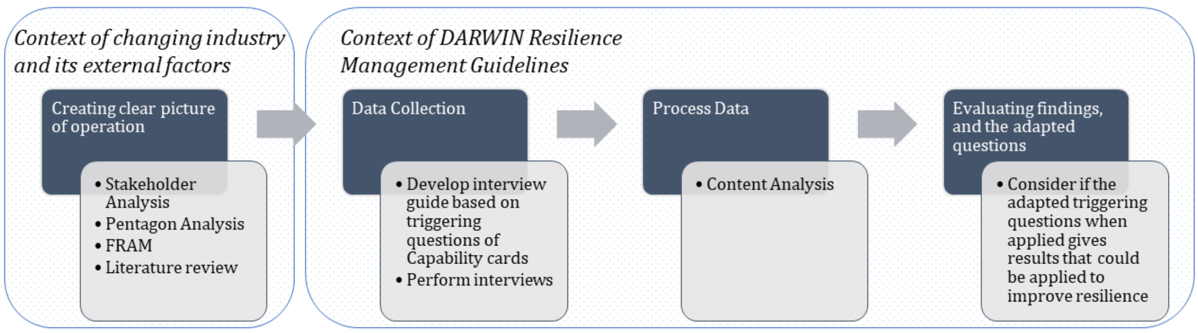

Figure 3.1: Methodical approach

Following, the four main steps are further defined.

1. **Understanding the operation**:
   This step helps develop an understanding of the operation, and the systems, humans, organization and stakeholders involved. This lays the foundation of information to apply when adapting the triggering questions from the DRMG, and creating the interview guide.

In this step important human, technological and organizational factors are considered. The understanding of results from the analyses are framed by the industrial context and its external factors as presented in chapter 1. Stakeholder analysis, Pentagon analysis and the Functional resonance analysis method are applied, and a literature review will be performed.

1.1 *Stakeholder Analysis*: The case of the master thesis involves multiple stakeholders, and a stakeholder analysis helps identify these. The analysis can highlight the different parties expectations, their role in the operations and identify users of the guidelines.

1.2 *Pentagon Analysis*: The Pentagon Model can be used to perform an organizational analysis. The goal is to emphasis challenges and opportunities of the operation related to various aspects of the organization. Here results from the project thesis will be used in the analysis, as well as new information. In addition to the challenges, methods and tools from Resilience Engineering and management will be presented as possible ways to deal with the challenges.

1.3 *FRAM*: The Functional Resonance Analysis Method can help shed light on the variabilities in everyday operations, and is a way to describe various possible outcomes. The FRAM analysis takes a systemic view, and considers functional resonance in the system.

1.4 *Literature Review*: A literature review on remote operation, with focus on onshore control rooms, was performed in the project thesis. As the subject of the master thesis changed focus toward remote operation of drones, a small literature review was performed that focus on challenges and opportunities related to drones will be performed. Relevant literature related to use of drones in various sectors and industries will be gathered. The industry could learn from use of drones in other industries, and experiences from use of aerial-, landbased- and underwater drones.

2. **Data Collection**:
In this step an interview guide will be developed containing triggering questions related to the chosen capability cards. The interview guides will be applied in a set of interviews with relevant managers from the oil company.

2.1 *Interviews*: Qualitative Interviews to gather data applying adapted triggering questions related to the three chosen capability cards. Interview guides will be constructed based on the foundation laid in step 1. The interviews will be transcribed, and the content will be further analyzed.

3. **Process Data**:
The data gathered through the interviews will be processed and analyzed in the light of the background information and the DRMG. The interviews will be transcribed, and further analyzed using content analysis. Categories and sub categories for the analysis will be found based on the background information found on the operation, and the CCs.

4. **Evaluating findings and adapted triggering questions**:
The findings will be compiled, and considered as a whole in the context of the DRMG. It will further be discussed regarding the quality of the adaption of the triggering questions, and whether they could be applied to improve the resilience of the operation. Possibilities for implementation of the guidelines are also discussed.

Following is a detailed explanation of the methodology used, as well as a description of what was done through the different steps for this thesis.

3.1 Understanding the Operation

The first step of the method was to create a clear picture of the operations described in section 1.2, through applying stakeholder analysis, Pentagon analysis, FRAM, and performing a focused literature review. The findings from the methods were further used as background information when commencing with the data collection. The implications of findings regarding resilience were considered throughout the results.

3.1.1 Stakeholder Analysis

The Project Management Institute defines a stakeholder as *individuals and organizations who are actively involved in the project, or whose interests may be positively or negatively affected as a result of project execution or successful project completion* (Committee and Institute, 1996). As stakeholders have the potential to affect the operation in the case, and thus the resilience of the operation, it is helpful to perform a stakeholder analysis.

A stakeholder analysis is carried out in several steps. The analysis gives an understanding of what stakeholders the company has, what their expectations are, their ability to influence the company as well as their willingness to collaborate, and finally helps establish strategies for managing the stakeholders. Managing stakeholders requires a continuous iterative process, where the stakeholders and their expectations are monitored. Here a stakeholder analysis has been performed to map out relevant actors with influence in regards to the case.

First, different actors that have stakes in the UID development project and operations have been identified. This was done through brainstorming, going through relevant documentation, and with help from people who have knowledge of the operations. Further, the role of these actors was divulged by **classifying** the stakeholders. The classification scheme proposed by Murray-Webster and Simon (2007) was used. This model assesses stakeholders in three dimensions;

1. Their power or ability to influence in the operation. This may be their potential to influence derived from their positional or resource power in the organization, or may be their actual influence derived from their credibility as a leader or expert (Murray-Webster and Simon, 2007).
2. Their interest in the project or operation, measured as the extent to which they will be active or passive (Murray-Webster and Simon, 2007).
3. Their attitude towards the project or operation, measured by the extent to which they will ‘back’ (support) or ‘block’ (resist) (Murray-Webster and Simon, 2007).

This classification gives eight categories of stakeholders. These can be seen in figure 3.2. Murray-Webster and Simon have proposed strategies to handle each of the stakeholder category (Murray-Webster and Simon, 2007):

1. **Savior:** Due to their high impact profile its important to pay attention to these actors, and keep them on the supportive side.

2. **Friend:** By using these actors as sounding boards or associates, their full potential can be utilized.

3. **Saboteur:** For these stakeholders, Murray-Webster and Simon proposes to engage the actors, this in order to disengage them. Further they mentioned that companies should be prepared to tidy up after them.

4. **Irritant:** The strategy proposed to manage these stakeholders is to control potential threats by engagement.

5. **Sleeping Giant:** These stakeholders should be involved to awaken their full potential.

6. **Acquaintance:** These actors should be provided with information on a need-to know level.

7. **Time Bomb:** Should be understood, to disarm before the bomb goes of.

8. **Trip Wire:** Should be understood, to stay clear of tripping on the wire.

The **expectations** of the actors were identified and mapped out. This was done through brainstorming, document review and feedback from people with knowledge of the operation. The Kano model was used to better understand the expectations. This model makes it easier to focus on the most important expectations, by presenting different types and levels of stakeholder requirements. The model can be seen in figure 3.3. Based on the information gathered, decisions can be made on the **strategy** for involvement and cooperation with the different actors (Andersen and Fagerhaug, 2001).

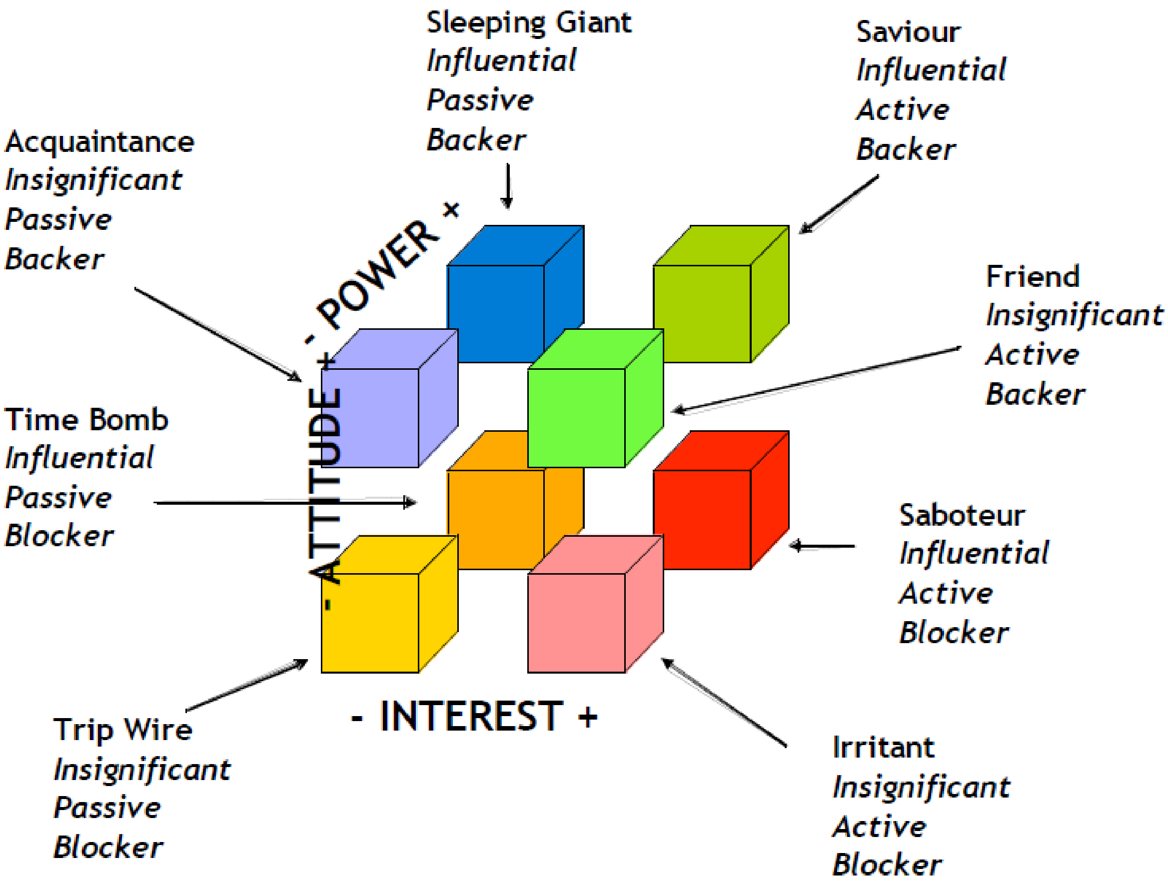

Figure 3.2: Stakeholder Classification as proposed by Murray-Webster and Simon (2007)

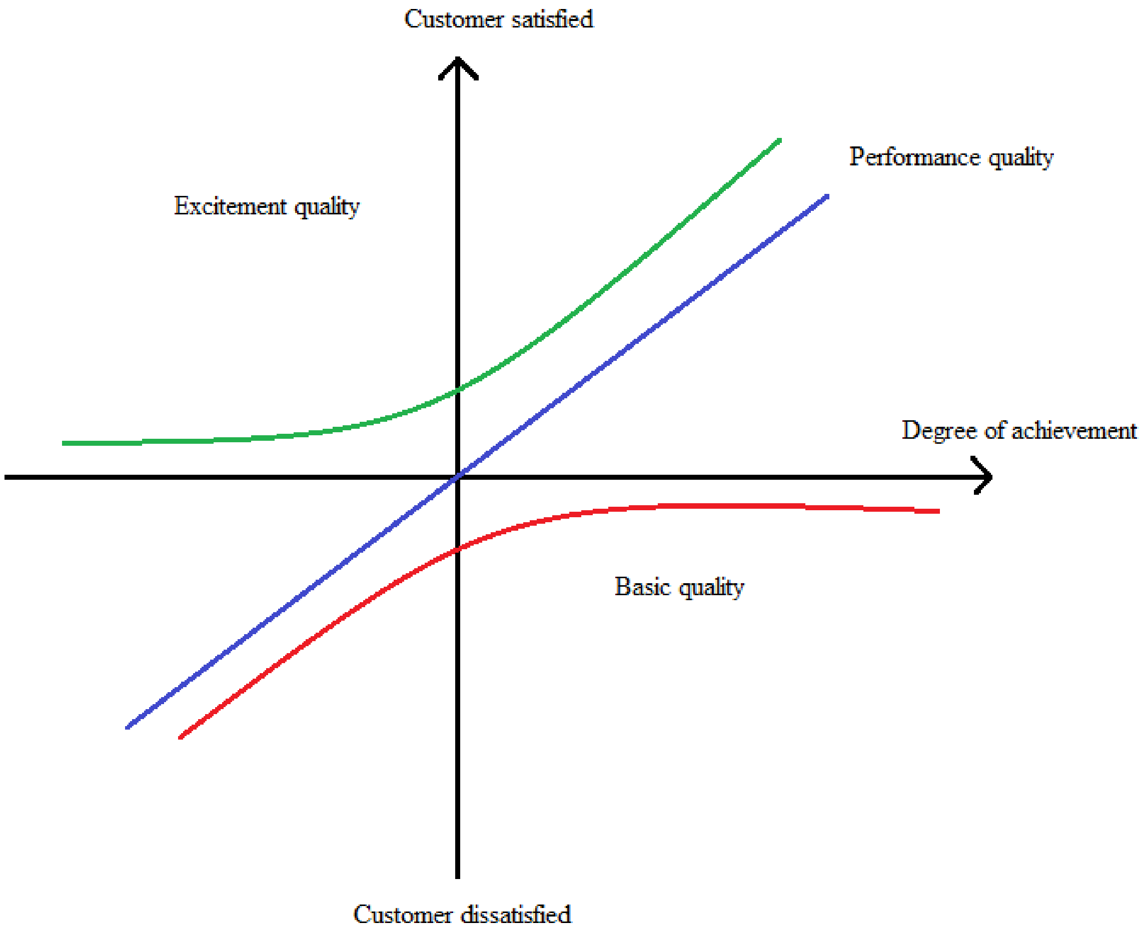

Figure 3.3: Kano Model for Stakeholder Expectations (Andersen and Fagerhaug, 2001)

The most central stakeholders, with the most influence in the operation, have been considered in the light of the DRMG. Especially considering coordination between stakeholders, and when parts of, or entire operations are carried out by a supplier. This can help divulge areas of the relations with different stakeholders that should be considered when applying the DRMG to the operation. The results of the stakeholder analysis were considered when adapting the triggering questions, especially from the *sharing information on roles and responsibilities* capability card.

3.1.2 Pentagon Analysis

The increasing use of new technologies, making operations gradually more remotely operated or automated, makes processes and operations in the Oil and Gas industry more complex and interconnected. The systems surrounding the operations are complex sociotechnical systems. A sociotechnical system is a systems where people play an important role in, or has relations to the system. These systems are comprised of a combination of different elements such as; hardware, software, human, management and organization, and the surrounding environment (Rausand, 2011). This is visualized in figure 3.4.

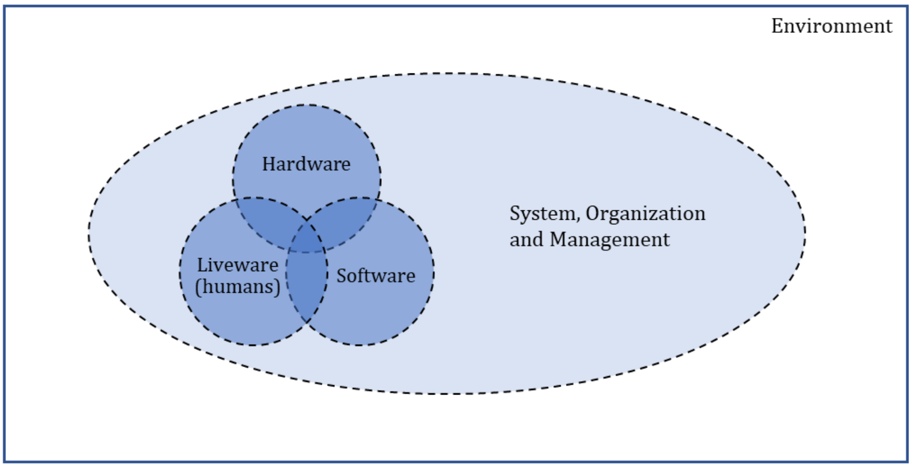

Figure 3.4: Sociotechnical systems. Based on figure by Rausand (2011)

To gain a better understanding of the elements in the sociotechnical system, analytical models can be used. For the thesis, the Pentagon model was applied to map out and better understand the elements of the organization involved in the UID operation. All the elements of the pentagon analysis were considered in the context of the DRMG. Various challenges and opportunities were identified, and further considered regarding how they affect the resilience, and how the guidelines may be applied to deal with them.

3.1.3 The Pentagon Model

The Pentagon model is an analytical tool developed for organizational analysis. The goal of the analysis to acquire a more in-depth understanding of complex interrelations in organizations. The model was developed by Per Morten Schiefloe, and can be used to analyze systems, individuals and groups in an organization. The model divides organizational variables into five categories; formal structure, technology, culture, interaction, and relationships and networks. The categories are explained in table 3.1. All the variables are interrelated, and thus will influence each other. Importance of the different variables will vary with situation, as well as what aspects are in focus in the analysis (Schiefloe, 2018). Understanding your organization is important to face challenges, and exploit opportunities when they arise. The model is visualized in figure 3.5.

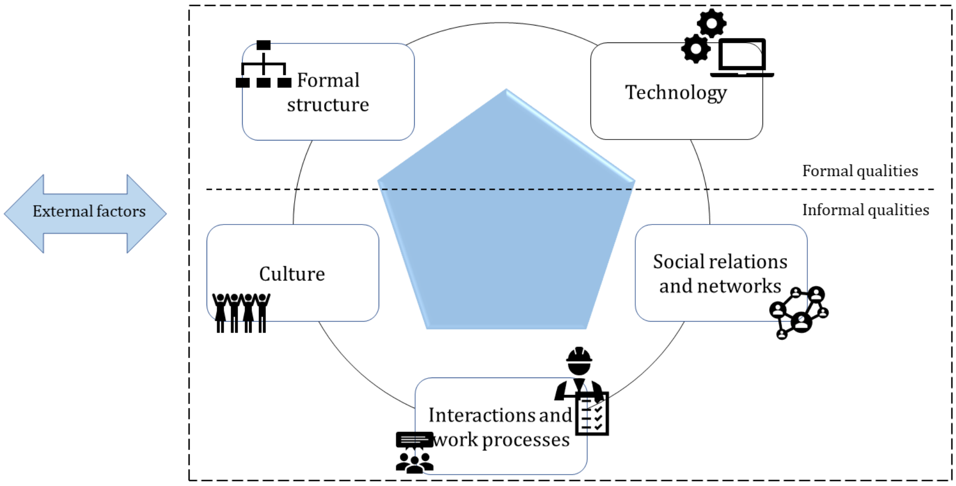

Figure 3.5: The Pentagon Model. Based on figure by Schiefloe (2018)

Table 3.1: Description of the different categories in the Pentagon Model

Category of Organizational Variables	Description
Formal Structure	Consist of the organization's structure, how responsibilities are distributed between roles and departments, and how authority is distributed across different levels in the organization (Schiefloe, 2018).
Technology	Consist of equipment and technology used by the organization to perform their operations (Schiefloe, 2018).
Culture	Elements such as values, attitudes, practices and symbols, concepts and language, which affect human behavior, decision making, norms and work (Schiefloe, 2018).
Interaction	Considers how humans within the organization relate to each other, which is fundamental to a work process (Schiefloe, 2018).
Relationships and Networks	Is important for the humans working in the organization, as informal relationships can connect people in an organization in different ways (Schiefloe, 2018).

A Pentagon Analysis was performed to map out the different variables of the organization that are involved in the UID operation. Information from the stakeholder analysis, input from people with knowledge of the operations, as well as findings from the preceding project thesis were used to identify elements within each variable, as well as opportunities and challenges related to the variables. Further, resilience was considered as a sixth element placed in the center of the pentagon, as a managment approach. Theory, methods and solutions for implementing or improving resilience were identified in the project thesis, and based on this a process for implementing resilience to handle the challenges and opportunities was suggested.

3.1.4 The Functional Resonance Analysis Method (FRAM)

The Functional Resonance Analysis Method (FRAM), is a method developed by Hollnagel for modeling of performance variability in non-trivial sociotechnical systems. The method can be used to develop an overview of, and analyze what might go wrong in, the work activities for the remote operation (Hollnagel, 2016e), (Hollnagel et al., 2010). The FRAM can give specific variabilities that might affect the resilience of the operation for a defined set of functions and activities to be considered.

The method is based on four basic principles. These are presented in table 3.2.

Table 3.2: The four basic principles of FRAM

The four basic principles of FRAM	
The Principle of Equivalence of Success and Failures	Explains failure as a cause of necessary adaptions to cope with under-specifications in complex real-world systems (Hollnagel et al., 2010).
The Principle of Approximate Adjustments	People must adjust their performance to current conditions. These adjustments are viewed as approximate, due to limited resourses and time. (Hollnagel et al., 2010)
The Principle of Emergence	There will always be a certain element of variability in normal performance. The Principle of Emergence states that accidents and malfunctions can be caused when this normal performance variability in multiple functions unexpectedly combine, creating disproportionate consequences (Hollnagel, 2016f).
The Principle of Functional Resonance	Hollnagel (2016f) describes functional resonance as the detectable signal that emerges from the unintended interaction of the normal variability's of many signals

In FRAM, a function represent the activities or acts necessary to produce a certain result. This activity can be a task performed by people, by an organization, a technical system or sociotechnical system. Each act or activity (function) can be described either as foreground or background functions.

- **Foreground functions:** are functions that may affect the outcome of the event or process studied (Hollnagel et al., 2014). Foreground functions need to have established output in addition to other aspects.

- **Background functions:** are functions that under the operation or situation considered can be assumed to be constant. And is typically something utilized by the foreground functions (Hollnagel et al., 2014). Background functions have only output or only input established. When there is only input, it can be referred to as a sink.

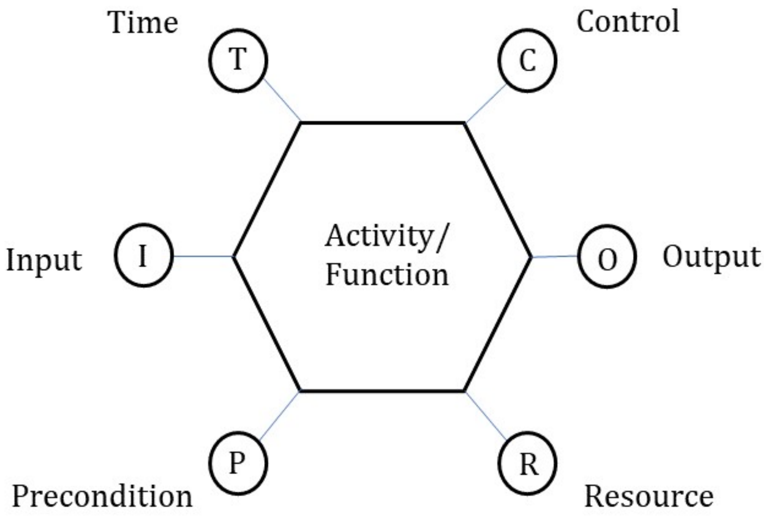

Figure 3.6: How FRAM visualizes a function and its aspects

Each function is defined and related to other functions through six aspects (Hollnagel et al., 2014). The six aspects can be seen in figure 3.6. The aspects are explained as follows;

1. **Input:** The input represent what initiate the function and/or is utilized or converted to create the output. (Hollnagel et al., 2014).
2. **Output:** The Output represent the result of the functions action (Hollnagel et al., 2014).
3. **Precondition:** Represent conditions that must be in place before a function can be performed (Hollnagel et al., 2014).
4. **Resource:** The resource, or the execution condition represent something necessary or utilized by the function (Hollnagel et al., 2014).
5. **Control:** Represent aspects that manage or regulate the activity/function (Hollnagel et al., 2014).
6. **Time:** The time is all temporal aspects that affect how the function is performed (Hollnagel et al., 2014).

FRAM was used to identify the potential variabilities in the UID operation.The information applied when building the model and perfoming the analysis, was gathered by conversations with persons involved in the development of the UID operation. A document review consisting of three documents was also conducted. The following documents were reviewed;

- Coordinating repair and modification of offshore production systems - The role of the project manager (Hepsø, 2002)
- “Boundary-Spanning” Practices and Paradoxes Related to Trust among People and Machines in a High-Tech Oil and Gas Environment (Hepsø, 2008)

- Subsea operation and maintenance in Statoil UPN -An as-is description of roles and work processes (Hepsø)

The FRAM was visualized graphically by the use of the FRAM Model Visualizer (FMV), a software tool developed by Rees Hill (Hollnagel, 2016a). First a model of the UID-inspection, and its sub-activities was developed, the next step consist of mapping the interrelations between the sub-activities. The following analysis steps where conducted;

1. In the first step the possible essential functions in the system were identified and described. Each function was then characterized with the use of the six basic characteristics. The first version should only contain the essential aspects, and can be modified further during the analysis (Hollnagel, 2016e). Arriving at the finished model usually goes through iterations of different versions of the model. This was also the case when working out the model for the thesis. When working on the descriptions of functions, aspect and variables, necessary changes were identified and implemented.

2. Further the consistency of the model was checked. A FRAM model can be said to be finished when there are no loose aspects (not related to another function), meaning the model is consistent (Hollnagel et al., 2014). The consistency check is done automatically by the FMV.

3. Next, the potential and actual variability in the model functions were identified. These where added in the FRAM model visualizer, and further described in detail. The FRAM consideres variabilities related to human, organizational and technological factors.

4. Next, the functional resonance was defined, based on the identified potentials for functional variability, dependencies and couplings in the FMV (Hollnagel, 2016e). As mentioned, the functional resonance shows the outcomes of unintended interactions of variabilities (Hollnagel et al., 2014).

3.1.5 Literature Review

To gain some insight into some important topics related to drone operations, a focus literature review was performed. There are different methodical approaches to a literature review. Systematic literature reviews present a systematic method for identifying, evaluating and interpreting all relevant research that is available, related to a given research area or question that is of interest (Keele, 2007). The drawback of this method is that it requires a substantial effort compared to a traditional literature review. Due to time constraint for the master thesis, a full systematic literature review was not possible. Here a small review has been performed, with strict exclusion and inclusion criteria to limit the number of articles.

The literature review was performed through five steps;

1. Definition of research question(s)
2. Conducting search
3. Inclusion and exclusion
4. Classification and data extraction
5. Analysis

Step 1: Definition of research question(s)
This step is the most important step of the study. The questions will set the scope for the study, and guidelines for conducting the search. The search process identifies studies that can help highlight the research questions. It also sets guidelines for data extraction and analysis, such that it is performed in a way that helps answer the question(s) (Keele, 2007).

The following research questions were set for the literature review:

- RQ1: How does various industry approach communication in operations of drones?
- RQ2: How does various industry approach solutions for docking and charging in drones?
- RQ3: How does various industry approach execution of mission planning?

These questions were selected based on discussions with supervisor on topics of interest regarding drone operation.

Step 2: Conduct search
Before conducting the actual search, methods that are to be used have to be specified. This includes choosing what databases to use for the search, the search strings to be used (keywords and combinations of these), selection criteria, and strategy for data extraction and analysis. The reason for specifying all these things before the search is conducted, is to reduce the possibility of researcher bias (Keele, 2007). All this was set up in a review protocol, which can be seen in appendix B.

The search was conducted in the databases Scopus and Web of Science. A pilot search was performed to test the search strings, and necessary adjustments where made. The resulting articles from the search were constrained with language, year and type of paper constraint, before the remaining list of articles were downloaded and structured using excel. A search log from the primary search can be seen in appendix C.

Step 3: Inclusion and exclusion
When the primary search has been performed, a screening process (inclusion and exclusion) should be performed. Here, inclusion and exclusion criteria set in the review protocol are used to exclude irrelevant papers (Keele, 2007), (Petersen et al., 2008).

After the initial constraints that were set during the search, a total of 69 papers where found. These were further considered by the students, to asses whether the paper should be included for data extraction. The abstracts were considered, and the papers were set as yes, no or maybe. Articles set to maybe were further considered by both students. The exclusion and inclusion criteria were set quite strict due to time constraints. The final set of papers after inclusion and exclusion consists of 18 papers.

Step 4: Classification and data extraction
Before starting to extract data from the papers chosen in the exclusion and inclusion step, a classification scheme should be created. The classification scheme sets guidelines for the data extraction, as it defines the categories used for the final analysis of the articles. A good way to construct the schemes is by going through paper abstracts and finding keywords, or creating categories based on the research questions (Petersen et al., 2008). The focus for the analysis

has been on the challenges and opportunities(solutions) that drones face, especially focusing on the areas charging, docking, communication and mission planning.

When the classification was established, the data extraction was performed. To perform the data extraction as structured and organized as possible, a data extraction form was used. This was done using excel. The extraction was performed by both students.

Step 5: Analysis
Through analysis the extracted data will be collated and summarized to help answer the research questions (Keele, 2007). For the thesis, a qualitative analysis of the content of the articles was performed. A content analysis is an analysis of categories. It divulges what categories can be found in a text, and what content can be found within the categories (Jacobsen, 2005). Findings within the different categories in the classification scheme were analyzed in the context of the master thesis to help give insight into the topic. The analysis results were presented in text and table format, and summarized and visualized using figures.

3.2 Data Collection and Processing

Following is the description of methodology that was applied for the development of the interview guide,performing the interviews, and processing the answers. To attempt adapting the triggering questions of the chosen capability cards to the case, triggering questions from the capability cards were selected and adapted based on the information gathered through step one of the method. Further, to test the adapted questions, qualitative interviews were performed. The purpose of conducting the interviews, was to consider if application of the triggering questions could prompt helpful reflections and evaluations on aspects of the operation. This could be in-depth knowledge and insight about events, course of events, opinions, assessments, arguments, decisions, measures or developments related to the operation case, that could contribute to improving resilience. In this way the interviews could reveal whether the adapted triggering questions could be applied to improve the resilience of the operation, and give inspiration on how the resilience guidelines can be implemented. The interview process can be divided into the following three steps; preparations, conducting the interviews, and processing of the data. Following is a description of how the steps were performed.

3.2.1 Preparations

Through the analyses described in section 3.1, complemented by guidance from supervisor, a foundation of background information on the operation was established. The background information provide an understanding of key parts of the operations, related to both human, technological and organizational factors in context of the industry and its external factors. This information was utilized in the process of developing an interview guide with adapted triggering questions from the chosen capability cards in the DRMG.

The interview guide had to be developed. In this process the three chosen capability cards were used as a starting point. On the wiki page of the DARWIN project, all the CCs are explained. For each theme you can access the different topics, and get further information. One of the things provided in the wiki are a set of *triggering questions* for each topic (DARWIN, 2018b). These triggering questions formed the basis for the interview guide. A relevant set of questions where chosen, and adapted to fit to the case. The capability cards contain triggering questions that apply to different phases of a crisis, before, during and after. Here it was chosen to focus on adapting the before crisis questions. The main reason for this is that the operation from the case has not yet been implemented for use. Questions for during and after operation would be more difficult to get good answers to at the current time. The number of questions chosen also had to be limited due to time constraints on the interview. The most interesting questions were selected based on the picture of the operation formed through the analyses previously performed. The questions where somewhat simplified, to make the interview questions as comprehensive as possible. It was important to consider that while the interview subjects are experts on subsea and UID operations, they might not be familiar with the field of resilience. An other important thing was to ensure that the questions were not to leading. Leading questions will induce the subjects to answer in a certain way (Jacobsen, 2005). The questions should leave room for the subjects to voice their own opinions. As the questions are *triggering*, they are somewhat leading in nature. This is to prompt reflections on specific aspects. However, the questions had to be formulated such that they did not specifically prompt answers as the interviewers see fit.

It was decided to perform *elite interviews* to test the adapted triggering questions in the interview guide. Elite interviews are with people who are considered as leaders or experts within a community, and are usually in a position of power (Jacobsen, 2005). An important issue when performing elite interviews is who to interview, and obtaining access to these interview subjects (Jacobsen, 2005). Access to relevant subjects was organized by the help of supervisor with relevant acquaintances.

The subjects were invited to interviews by email. Eleven subjects where invited, and seven responded and participated in the interviews. As all subjects speak Norwegian, it was decided to perform the interviews in Norwegian. This facilitates better flow of the interviews, as it will feel more natural for the subjects when they can reply in their own language. Due to busy work schedules and varying work places, the interviews were planned performed over Skype. The planned duration for the interviews was one hour. Interview subjects got to suggest time slots for the interviews, that fit into their schedule.

To ensure that rules and regulations related to privacy and data protection were adhered to, an application was sent to NSD, Norwegian Centre for Research Data. NSD go through the application, and assesses whether the research project meet the requirements of data protection legislation, and offer guidance to ensure the requirements are met (NSD, 2020). The application to NSD was approved for the project.

3.2.2 Conducting the Interviews

As mentioned, the interview subjects were not all familiar with the field of resilience. As this was an important theme in the interviews, a short email providing some background information and clarification of terms was created and sent to the interview subjects. It also contained a brief case description. The information provided can be seen in appendix D. One requirement from NSD is that the interview subjects have to read through and sign a statement of consent. This was also sent to the subjects to be signed before the interviews. The statement of consent can be seen in appendix E.

Both students participated during the interviews. The interview questions were divided between the two students, so that each were responsible for their own half of the interview. The interviewers made themselves familiar with the interview guide. The questions were asked, and the interview subjects were allowed to speak freely. Follow up questions were used if necessary. The interviews were recorded using an audio recorder. This allowed for the interviews to be transcribed after they were conducted, and ensures that no data is lost. In addition, the interviewer took notes during the interviews.

3.2.3 Processing the Data

The first step of processing the data from the interviews, was transcribing the audio files from the interview. The transcribation was performed by both students. Excel was used, and the transcribation was organized by the questions in the interview guide. Through the transcribation word for word of what was said was recorded.

When the audio was transcribed, an analysis of the text was carried out. A content analysis was performed for the interviews, as for the literature review. Categories for the analysis can be found with a starting point in the data, or be the researchers own categories (Jacobsen, 2005). For the interviews, most of the categories were given from the interview guide. The main categories are the topics from the CCs, and sub categories for the topics were found. The categories considered are shown in table 3.3. Analysis was performed, and quotes from the interviews were presented in tables to illustrated the findings.

Table 3.3: Categories for analysis

Assessing Resilience
Identifying sources of resilience
• The adaptive capacity • Resources • Monitoring • Dependencies and interactions • Learning
Noticing Brittleness
• Lack of resources • Lack of information • Goal conflicts • Constrains and bottlenecks • Difficulties to adjust
Supporting Coordination and Synchronization of Distributed Operations
Sharing Information on roles and responsibilities
• Involvement of organizations • Coordination mechanism • Impact on organization • Internal dissemination of changes • Sharing roles between human and machine

3.3 Limitations and Criticism of the Method

The objective of the thesis is to adapt and apply the DRMG to the case operation. There are however some aspects of the method presented in this chapter that can be subject to criticism. The adaption of the triggering questions is made based on information gathered through analytical methods. In a well established operation, this information could be supplemented by input from documentations and participants from the operations, which would be more reliable data to base the adaption on. This is not possible for the operation in the case, as it is still being developed. Another point of criticism is that no revision was made to the triggering questions after applying these in the interviews. The revision would help create a set of questions that better trigger reflections and evaluations. Due to time limitations, the revisions were only suggested.

The individual methods and analyses applied also have limitations, these are further discussed in the following sections.

3.3.1 Criticism of the Stakeholder Analysis

Stakeholder analysis usually include all of the involved actors, but due to the time limitation of the thesis, only generic groups of key actors were considered. This means that among others, stakeholders related to various departments in the oil company are not presented in the analysis. Also, stakeholder analyses are usually performed based on a brainstorming within a group of individuals from different parts of the organization, but due to the limitation of time and lack of experience, the analysis is based on guidance from the supervisors of the thesis. This affects the choice of stakeholders presented, and the identification of their expectations.

The Kano model that was utilized, is based on the assumption of reasonable stakeholders with rational expectations and requirements towards the operation, and the company. But some stakeholders might have individual interests towards the operation and company that do not represent the best interest for the organization. If some actors have such interests, the results of the Kano model will not cover these.

Murray-Webster and Simon's classification scheme is one of many models for analysis of stakeholders, where the models include different elements of the relationship between the operation and the actors. Therefor not all elements are considered in the analysis. For example, one element that could have been relevant in the analysis is legitimacy, used as an indicator on the actors right to be heard, due to them being affected by the change that is to be conducted. Legitimacy is often applied to prioritize the importance of the actors (Mitchell et al., 1997). Due to the time limitation of the thesis, only the elements included in the presented methods in 3.1.1 were included. In a complete stakeholder analysis, for the purpose of managing stakeholders, it could be considered to use more than one model for classification to cover more elements.

3.3.2 Criticism of the Pentagon Analysis

The pentagon analysis is a good way to analyze organizations to get an understanding of them. The model was created based on reasoning gathered through research, that found that most organizational capabilities can be analyzed within the categories in the pentagon (Schiefloe, 2018).

However, while the model is good for identifying organizational capabilities and challenges, and how there are interrelations between these, it does not show how the various factor might affect each other when they interrelate.

The analysis was based on information gathered in the project thesis, as well as input from a person with insight into the operation. Further, information could have been gathered through studying governing documentation, and getting more familiar with the organizations involved.

The analysis could have gone more in-depth to look at the organizational aspects of the different inter organizational departments, as there would be differences in between these. However, tough the analysis identifies that there are different departments involved, it does not go into detail on differences between these and the interrelation between them. To perform a thorough analysis, each department could be considered on their own, and than look at interrelations between them.

3.3.3 Criticism of FRAM

The FRAM analysis is a relatively new method, and as such can be both time consuming and difficult to understand (Hollnagel, 2016d). The analysis was performed by two students, with basic understanding of the principles, with guidance from supervisor. As this is the first time for the students to apply the method, it was done through a trial and error process.

The data needed for the FRAM performed for the thesis was gathered through review of a couple of documents, as well as input from a person with knowledge of the operation. Ideally, the data for the FRAM should be obtained through involvement of the people who perform the operation (Hollnagel et al., 2014). Interviews or workshops with relevant personnel would be the best way to gather data on the activities that are being investigated.

The FRAM performed was limited to look at the performance of the operation from the need for inspection to the after work review following the operation. There are functions surrounding the operation, specifically organizational functions, that are not considered by the model. If these functions were added, more details could be disclosed about the coordination surrounding the operation. It was chosen to not include these, as the pentagon analysis already had focused on the organizational factors of the operation. The analysis performed only focus on one instantiation of the operation. Additional types of inspections and tasks could be added to the model, and other instantiations could be analyzed to see functional resonance for different scenarios.

In practice, the FRAM model is often built through many iterations (Hollnagel et al., 2014). The final model in the thesis did go through some changes, but closer investigation and gathering of data from better sources could still improve the model further. Due to the time limitations of the thesis, it was decided to go with the current model and the input it provides. If the triggering questions at a later stage are to be further revised, the FRAM could be improved to help with this adaption.

3.3.4 Criticism of the Literature Review

Systematic reviews are more robust than literature studies with less structure, but are not immune to biases. Bias can show up throughout the literature review, from the beginning to the end. Four types of biases have been assessed for the literature review (Keenan, 2018);

1. Bias in review design
2. Bias in locating papers
3. Bias in paper selection
4. Bias in analyzing papers

Bias in the review design can be introduced when setting the research questions and search strings for the review. The strings are formulated to give outcomes that are desired, but might be affected by preconceived ideas about what the literature covers. This affects the choice of keywords, and combinations of these in the strings (Keenan, 2018). An example of this is how in this review, a specific set of themes where chosen; communication, docking, charging and mission planning. The search strings where not thoroughly tested. One pilot search was performed, where small changes were made to refine the search. However, to ensure good quality of the search strings further tests could have been made. In this way strings that are to specific, or not specific enough could have been improved. Another thing to consider is the search terms that were used. The literature review set out to gather inspiration and information from other industries. The different industries might use different terms. Synonyms were identified, but some terms that are industry specific might be missing.

Bias in locating papers is related to where and how you look for papers (Keenan, 2018). Only two databases was used for the search, Scopus and Web of Science. Web of science only gave 7 of 69 resulting papers, and four of these were duplicates from the papers found in Scopus. Some of the reason for this can be the type of literature that is covered by the database. From the search we encounter two types of errors; type-I and type-II errors. Type I error is related to the scope of the search, and represents the papers that are desired but not found. This is all the papers that are not present in the databases, and all papers not found due to formulation of the search strings. Type-II error is related to the degree of precision in the search, and represents papers that were included in the search that are not relevant (Kjellen and Albrechtsen, 2017). Through exclusion and inclusion criteria this type of error has been reduced. The study also have some exclusion criteria integrated in the search. Only papers from the five last years were included, and all papers not in English or Scandinavian language were excluded. The search also excluded books and book chapters.

The last bias appears in the results of the study, as a consequence of only choosing to look at the findings that are significant (Keenan, 2018). Only a selected few articles where considered, however the chosen papers where thoroughly analyzed. There might also be bias in how the results are interpreted by the reviewers, as it is affected by the knowledge and insight of each individual. How the classification schemes are defined, can also represent bias. When the categories are defined, it is easy to not look for information that falls outside these categories.

3.3.5 Criticism of Interview Process and Data Processing

Interviews can be subject to various bias. There are two main types;

1. Bias arising in content or wording of questions (Waterfield, 2018)
2. Bias arising from interviewers and the way in which they ask questions and respond to answers (Waterfield, 2018)

Bias in the content and wording of questions could appear in the questions in thesis. The questions were adapted from the triggering questions of the DRMG. The students understanding of the questions could have affected how they where adapted, and some of the meaning of the questions could have been lost or misinterpreted. Further, the questions were also translated to Norwegian, where again the wording of the questions could be affected. As mentioned, leading questions should be avoided in interviews. However, in this thesis the questions are meant to induce reflections and evaluation of specific themes, and sometimes leading them to the right themes is necessary. Therefore, some of the questions might be slightly leading in nature.

Another bias in the content can be found in the case information given for the interview. To not take up to much time of the interviewees, and not to confuse them with to much info, the information was kept short and simple. Some examples were given for the subjects understand the context. It is possible that this leads to the information being to leading, and the subjects being to focused on this information when answering questions.

The interviewers bias could come from the trust and relation built between interviewers and subjects. This could be affected by factors of the interviewer like age, sex, education, and professional background (Waterfield, 2018). For the thesis the interviews were performed over skype, and the interviewers did not meet the subjects in person. This puts some distance between them, and could also make them feel somewhat more safe. To establish trust, the subjects were sent information before the interview regarding use of personal information, and some information to allow them to prepare themselves. The interviews where started by the interviewers presenting themselves, and again running through the information sent out to ensure the subjects understood. The interviewers are students, which might affect how the subjects relate to them.

Another source of interviewer bias comes from body language, facial expressions, and how the interviewer talks when posing questions (Waterfield, 2018). As the interview is over skype, body language does not play the same role as when the interview is in person. However, the interviewers made sure to appear awake and ready, and sat upright and paid attention to the subjects. The interviews where performed in Norwegian, and the interviewers spoke in their own dialect to make the interview less formal. This allows the subjects to feel like they can be themselves. Bias can also come from how the interviewer emphasizes certain words of sentences to draw attention to part of the question. For some questions of the interview, this was necessary for the subjects to focus on the correct themes.

Interviewer bias could also come from the expectations and preconceptions of the interviewer. This could affect ho the interview is performed, as well as how the data is analyzed. For the analysis, categories where established in order to analyze the answers within these categories.

Quotes were chosen that gives a perspective interesting to the categories. Some information may be lost as it falls outside the selected categories. The expectations and preconception might also lead interviewers to ask follow-up questions, or give examples that promotes the subjects to give the answers the interviewers expect.

The interviews performed had a time limit of one hour. As the interview guide contains many questions, a priority was established so that the most important questions where asked in the time frame of the interview. This means that some of the questions where not tested, and some where only posed to some of the subjects.

The results of the interviews are not generalizable, as the interview questions are created for a given case. The answers given are therefore specific for this case, although some generic reflections could be made that could be utilized to say something about other similar operations.

Bias in the results can also come from differences between the subjects. One source of this could be that the subjects have different backgrounds, and have different interest in the operation being investigated. The understanding of the operation, and how it will work, could affect how the subjects understand the questions and how they answer. The differences can also come from differences between departments in the company, as the subjects come from various departments.

Chapter 4

Analysis and Results

In this chapter results from the various analyses performed is presented, compiled and put in context to help shed some light on the problem statement. The first part of the results is focused on creating a picture of the operation, while the second part focuses on the interview answers, and what reflections and evaluation were made by the subjects. The results are further discussed as a whole in chapter 5.

4.1 Understanding the Operation

This section presents the results of the stakeholder analysis, Pentagon analysis, FRAM, and the literature review through tables and figures. Implications of the findings regarding resilience have been discussed through the results. The information found forms a picture of the operation and various aspects of it. This was further utilized when developing the interview guide for section 4.2.

4.1.1 Stakeholder Analysis

To identify and understand the key actors that affect or are affected by the project and operation, a stakeholder analysis of the key actors was conducted. The key stakeholders were identified through brainstorming and input from the supervisors. The actors identified are illustrated in figure 4.1.

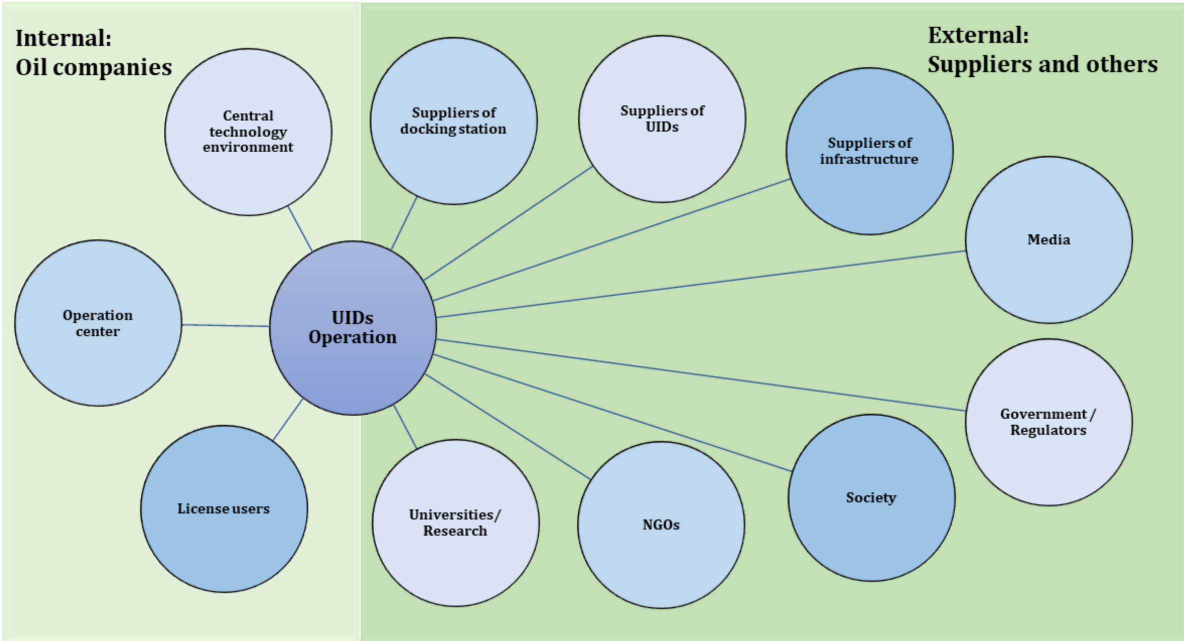

Figure 4.1: Stakeholder analysis for the project and the UID operation.

Two main categories of stakeholders were identified, internal and external. The internal stakeholders consist of three key subcategories; the company's central technology environment, its operation center and the license users. The external stakeholders consist of suppliers of the equipment and infrastructure necessary for the operation, and other actors with the potential to affect, or that are affected by the project or the operation.

Further, the roles of the identified stakeholders was classified by the use of Murray-Webster and Simon classification scheme. Table 4.1 shows an example of the classification of the *suppliers of UIDs*. The classification of the remaining stakeholders can be seen in appendix F.

Table 4.1: Classification of the suppliers of UIDs, by the use of Murray-Webster and Simon stakeholder classification scheme

Classification of *suppliers of UIDs*	
Suppliers of UIDs	
Power	***Influential*** The power of suppliers towards the operation depend on their marked position. If there are many suppliers to choose from the power of the suppliers decrease, and vice versa. Another factor is to what degree it is possible to switch between suppliers after startup of the operation, and the cost related to this. In the process of startup of the operation there are different suppliers to choose from. But the suppliers will take part in the development of the operation, and the remote operation of the UIDs. Therefor the supplier will have influence over the development, and might be difficult to switch out over time.
Attitude	***Backer*** The suppliers have a backing attitude towards the project and the developed operation, with the potential for sale of their product or service.
Interest	***Active*** The suppliers main priority is to sell their products, therefor they have a strong interest in the project and the further development of the operation. Also, the technology is new, holding potential for further improvements beneficial for the suppliers development of product.
Classification	***Savior***

Based on the actors identified classification, and Murray-Webster and Simon's recommendations presented in section 3.1.1, strategies were given for the stakeholder. Table 4.2 shows the strategy given for the *suppliers of equipment and infrastructure* and *operation center* stakeholders. Strategies for the remaining stakeholders can be seen in appendix G.

Table 4.2: Purposed stakeholder strategies based on the Murray-Webster and Simon classification scheme

Purposes strategies based on Murray-Webster and Simons classification scheme	
Suppliers of equipment and infrastructure	
Saviors	The suppliers of equipment and infrastructure are actors important to the project and operation, that should be held attention too and kept supportive.
Operation Center	
Friend	Friends are actors backing and having high interest in the project and the operation, but with little power. The purposed strategy for these actors are to use them as sounding board, to utilize their interest and knowledge regarding the remote operation.

To develop an understanding of the expectations and requirements the stakeholders hold towards the project and the remote operation, the Kano model was used. Examples for the *suppliers of UIDs* and *operation center* is given in 4.3. The expectations of remaining stakeholders can be seen in appendix H.

Table 4.3: Identified expectations and requirements of the *suppliers of UIDs* and *operation center*, by the use of the Kano model

Identification of expectations and requirements	
Suppliers of UIDs	
Basic	• Communication with the company
Performance	• Collaboration with company regarding further technology development
Excitement	•Exclusive agreement with company regarding delivery of UIDs • Be included in the company's media publicity
Operation center	
Basic	• Proper training and protocols for the new operation • Access to drones and resources when needed • Knowledge of the persons in charge and who to contact if needed • Stable network connection and UID communication • Reliable equipment and infrastructure
Performance	• Possibility to take part in the development of operation and protocols
Excitement	• Influence over the development and future work methods

The stakeholders in DRMG context

As mentioned in section 2.8.2, the roles and responsibilities of involved stakeholders need to be clarified to ensure that the management capability for the operation is sufficient. This require a knowledge of the actors involved, and their role and responsibility towards the operation. The most central stakeholders, with the most influence in the operation, have been considered in the light of the DRMG. This especially considering coordination between stakeholders, and considerations when parts of, or entire operations are carried out by a supplier.

In section 2.6.2 four types of resilient systems are mentioned, depending on their degree of resilience performance. Systems of the fourth kind have an ability to anticipate how the surroundings will respond to changes, and how this can affect the system. To achieve this the company need to understand the impact and the expectations of the actors involved. The analysis reveals the need for coordination and management of the various players and their expectations for the operation. Their impact on the resilience of the operation varies from nothing to a considerable degree. The coordination of the most critical actors can be vital for ensuring that the operation is successful, and can also help reduce the risk of conflicting goals in the operation.

4.1.2 Pentagon Analysis

The Pentagon analysis was made to exploree the functioning or characteristics of the organizational structure of the UID operation, and not the organization of the oil company or the suppliers as a whole. This means that different levels of the organization, and the relation between these, has to be considered. The model can help to enhance the understanding of the organization. Here challenges and opportunities are identified related to different variables and elements in the organization, which further can be applied to clarify where and how it might be possible to apply the resilience guidelines to deal with challenges, and how the opportunities that are identified can be taken advantage of. The model can also help when interpreting data on the operation from the other analyses performed following the Pentagon analysis.

Figure 4.2 shows the different elements that where identified for various variables, placed in the pentagon model. Challenges and opportunities related to the different elements within the the five organizational variables in the model, as well as external factors, can be seen in the tables in appendix I. These are further discussed following.

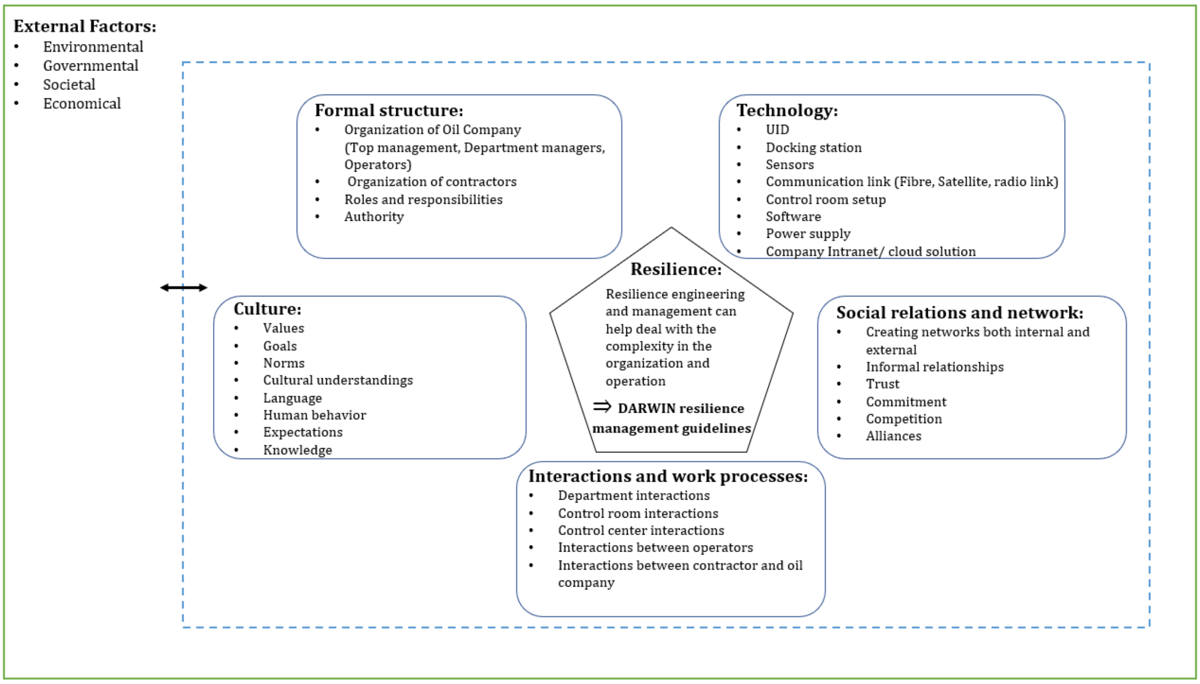

Figure 4.2: Pentagon analysis for UID operation

Formal Structure

The *formal structure* of the operations comprises of elements such as; different organizational levels in the company, roles and responsibilities, authority, procedures, reporting, internal requirements and decision making. Together these elements make up what is often referred to as the *organization* (Schiefloe, 2018). The formal structure offers different challenges for the operations, both related to internal organization, but also the organization of the contractors.

Many of the elements in the formal structure are interrelated. The levels of organization, roles and responsibilities and authority are all related to each other. These will again affect procedures, reporting, requirements and decision making. How the organization is “designed” will affect how these elements play with each other. For the UID operation events may occur where quick decisions have to made. If the operators don’t have the authority to make these decisions, and have to go through someone with a higher level authority in their own or other organization, this can cause unwanted consequences. If the decision is not time critical, it is possible to go through the process of decision making at a higher level, but then it is important that roles and responsibilities are clearly defined so that it is clarified who should make what decisions.

Procedures are important tools to make sure that operation is performed in a successful manner. Good procedures are developed based on experiences, and should involve people from different levels of the organization. They should also be updated when new experiences are made. This requires cooperation between organizational levels, and also a good organizational culture. The culture will be further discussed under the *culture* variable.

An important challenge identified from the formal structure is internal and external communication. Internally, communication has to flow across multiple organizational levels. Externally, it is important that the communication is good with various stakeholders (as identified in section 4.1.1). Communication with the contractors who are to conduct the operations is of particular importance. The organizational design is important to facilitate good communication. Insufficient internal and external communication can affect the operation, as it affects the ability to handle challenges and increased complexity in the operation. It would also affect the systems ability to respond, as quick and smooth communication could be critical when responding to expected and unexpected events.

Technology

Technology is an important variable in the UID operations. The technology covers all tools, in form of machinery, equipment and systems, that the operation depends on to be completed. The operation involves a range of technology. The function of these various technologies is key for the operation, and will effect the resilience of the system. Challenges like loss of communication, cyber attacks, failure of equipment and errors in software can cause delays in the operation, or hinder the execution of the operation as a whole. As such, the quality of the technology is important to consider. Possible failures in the technology should also be anticipated, and ensuring suitable responses to such events should be considered.

Another challenge to consider is how the technology is interdependent. This causes cascading effects when something goes wrong. A small software error in the control room, can stop the drone. A cyber attack on the drone, can lead into other important systems and reveal sensitive data. Error in sensor data, or communication delay while moving among critical components could cause collisions between the drone and critical subsea systems. Mapping out how systems interrelate and affect each other is key to avoid unwanted events.

The technology also offers new opportunities. The drones can more efficiently perform the operations than the current solution for inspection, and a range of sensors can be applied to gather large amounts of data. This constitutes a unique opportunity to learn, and as such improve the operation. This is also aided by the advancement of machine learning algorithms and software, that applies artificial intelligence (AI) for the system itself to learn and improve based on experiences. This will improve the systems ability to respond and anticipate, and thus make it more robust. The drones could obtain a higher level of autonomy (as described in section 2.1), reducing the need for operator involvement. This could help reduce human and communication related errors. The large amount of data also makes it easier to monitor both internal and external factors that will affect the performance of the operation.

As mentioned in section 2.3, the oil and gas industry has adopted Integrated operations as a way to deal with the change process in the industry. The work method facilitates use of technology, and is therefor a helpful approach when dealing with this organizational aspect in the UID operation.

Culture

An organizations culture will affect many of the other organizational variables. The culture is made up of many elements, as shown in figure 4.3. The culture forms how groups and individuals acts and behaves. If the company culture is poor, different challenges would surface, not only within the culture variable, but the other variables as well. The culture penetrates through the whole organization. Conflicting goals, misunderstandings, unwanted behavior and conflicts are just some of the consequences that could occur if the culture is poor.

The culture affects how an organization will react to challenges. If the organizational culture is good, they should have the ability to apply information, observations and ideas to solve problems as they arise. This should be true regardless of location, authority and roles. This involves that a persons position in the organizational hierarchy can change to deal with unexpected events. The culture also dictates how a person understands a situation, what priorities will be made and what work practices are complied with. This is crucial when it comes to the ability to anticipate and respond to expected and unexpected events.

The culture can also affect the degree of experience transfer and learning. Good organizational culture will allow for a good transfer of both knowledge and experiences. This ensures high quality of information, and promotes continuous improvement in the organization.

For the UID operation it is important to consider that the culture might vary slightly for different departments of the oil company, and that the suppliers culture might differ from that of the oil company. It is important that cultural aspects of the operation is communicated to all actors involved, so that there is a common understanding of the values, goals and norms of the operation.

Interactions and Work Processes

Interactions between organizations, groups and individuals is a prerequisite for all work processes involved in the operation. This involves both internal interactions between individuals and different organizational units, as well as external interactions with contractors, competitors and other stakeholders (as identified in section 4.1.1).

Internally, different departments that might want to use the UIDs would have to interact and make plans and schedules to ensure everyone's need can be covered without conflicts. There should also be a clear definition of priorities if there should be conflicting needs. Interaction is also necessary between the departments that will be using the UIDs, and the department that is responsible for the development of the concept. Unsatisfactory internal interaction could be due to poor leadership and management, or be connected to other variables like formal structure or culture.

Externally, interaction with the contractor is important to ensure that the operation is performed as planned and expected by the oil company. This could be in the form of handing over requirements and plans before an operation, or follow up during the operation. Poor communication, collaboration or/and coordination could cause misunderstanding, lower quality or failed operations.

The UID operation offers a good opportunity of inter-organizational collaboration. Exploit expertise of both contractor and the oil company to create the best operation and equipment. If the relation with the contractors is nurtured in the right way, it could constitute a win-win situation for both parties. This require that both organizations have coinciding goals, and work together to make the operation successful.

An other opportunity that arises with the interactions with competitors, is co-opetition. Co-opetition combines the benefits of competition and cooperation (Nalebuff et al., 1996). By combining the expertise and resources of different company's, a more effective solution for the drone operations could be designed. An example of this is if different company's could share the drones and drone stations, strategically placed between platforms. With more stations available, the drones could operate over larger areas, as charging could be done at other stations than just the *home station*. Such co-opetition could also lead to innovation and creation that solves issues related to technological challenges, and as such improving system robustness. Co-opetition also opens for exhange of knowlede and experiences, enhancing the ability to learn.

Relationships and Networks

From the formal structure and interaction and work processes variables, formal interactions between groups and individuals is considered. This considers how people interact as dictated by the organizational structure, and formal relationships. However, *informal relationships* connect people within organizations in different ways, and are also important to consider. Good informal relations can help create strong social networks that are helpful in the face of challenging situations. It can help spur on innovation and creation for better solutions, and promotes experience and knowledge transfer between individuals and groups. This variable is interrelated with the *interactions and work processes* variable, as interaction is a precondition for the formation of relationships and networks. The social networks form the basis for beneficial alliances and power.

Informal relations can also create challenges. If the relations are not good, there can be a lack of trust between individuals or groups within the organization, or between organizations. It might also affect the level of commitment in the operation. It would be a problem if such challenges where to arise between the oil company and contractors. They can cause power struggles, internally and externally. This causes negatively loaded interactions, and is unproductive use of time and effort.

External Factors

Including the *environment* in the analysis is important, as what happens within the organization will depend on the interface with the environment (Schiefloe, 2018). Rules and regulations enforced by governments, public opinion and social concepts, and market trends are all factors that could affect how a company operates. For example, the opinions of the general public can affect a company. They can lead to change in policies, and also affect the reputation of a company.

In the table in appendix I, external factors like the varying weather and ocean conditions have been identified as an environmental challenges. As the operations are located subsea, and the drones live on the seabed, the ocean conditions will not affect the drones much. However, it might cause difficulties in communication in the operations. The communication link, and challenges related to this, was also addressed as an element under the technology variable. An opportunity when it comes to the environmental element, is that the new UID operations have the potential of being more environmentally friendly than the current ROV operations. Having the drones live on the seabed removes use of vessels to deploy the ROVs, and saves fuel used to bring the vehicle from the surface to the seabed. The fuel (battery life) can then be more effectively used in the operation.

Regulations and classifications are also identified in the table. As explained in section 2.5, rules and regulations for the UIDs have not been developed. It is a challenge when it is not known what boundaries to stay within for the operations. Rules and classifications for ROVs can be used as a guide, and communication with the enforcing government is recommended. The UID system should also be designed to be as robust as possible, and should have the ability to adapt if changes in existing, or new regulations are to surface.

The societal and economical elements are interrelated. The UID operations offer the opportunity of cutting costs in the operations. This is achieved at the expense of job positions, as the number of operators needed will decrease. However, the operations might also open for new position. This could for example be related to data processing and development of systems to support this.

The Relations Between the Variables

Although the model divides the organization into five different variables, that interact with its environment, it is important to remember that these variables are not independent of each other. Sometimes the solution for challenges in one variable, could come from improving another variable. The formal structure will often define how interactions in an organization happen. Interactions are also affected by the culture, and one can also say the culture is affected by formal and informal interaction. Technology has changes how we work and interact internally and externally. In an analysis like this it is therefor important to see the organization as a whole, and not as the sum of its individual parts.

Resilience Guidelines in the Analysis

The analysis identifies many challenges. Some of the most prominent challenges are represented in the interaction and cooperation between the oil company and the contractor, the culture and its effect on individuals and groups in the organization, the ability to learn and the technology that constitutes a precondition for performing the operation. External factors also interact with the internal organizational ones. In this analysis, resilience management is proposed as an underlying mechanism to help deal with complexity and challenges in the organization and operation. In section 2.6.2 it is explained how there are four categories of resilient systems and organizations. The systems with the highest degree of resilience are referred to as *systems of the fourth kind*. These meet all qualifications regarding the resilience abilities; Monitor, respond, Learn and anticipate. All the organizational variables and their elements play a role in achieving sufficient proficiency within these.

The DRMGs can be applied as a starting point for an improvement process. In the successive project thesis, a literature review was conducted to map out how resilience engineering and management can be applied to address increasing complexity. The review found articles pertaining to five main categories;

1. Understanding Resilience (theory)
2. Guidelines and frameworks
3. Assessing the need for resilience
4. Implementing resilience in practice
5. Monitoring and assessing resilience in organization, process or operation

To improve resilience in the operation, it should be approached as a continuous process. This is similar to other management methods, that adhere to the PDCA (plan - do - check - act) principal. Starting from theory an understanding of resilience engineering and management, and the elements that make up a resilient organization or operation, can be built. The next step is creating, or choosing an already existing guideline or framework for assessment and implementation of resilience. Here the DRMGs can be applied. Capability cards like *Supporting coordination and synchronization of distributed operations* addresses the cooperation and interaction both internal and external. The *Assessing resilience* capability card addresses learning, and factors that affect this. When the guideline is chosen, the organization and/or operation has to be assessed to identify where resilience is needed. Further based on the need, and the guidance from the guidelines, a way of implementing the resilience has to be worked out. An example could be new systems for learning, or using resilience triggering questions before performing the operation. Lastly it is important to monitor the operations and organization, to assess whether the implemented measures actually contribute to improved resilience. Experiences can then be transferred, and theory and guidelines can be updated accordingly. New needs for resilience can surface, and thus new measures should be implemented. The process proposed is visualized in figure 4.3.

Figure 4.3: Resilience as a process to deal with challenges

4.1.3 Functional Resonance Analysis Method (FRAM)

In this section the results of the conducted FRAM analysis are presented. A FRAM model was constructed for the operation defined in the case in section 1.2. The model is limited to focus on the inspection operation in itself, and considers the operation from the *need for inspection* is identified, to the inspection is performed, and gathered data is stored in the oil company's data storage solution. 20 functions were identified for modeling in the FRAM Model visualizer. The FRAM model is somewhat generic, and does not go into detail of what kind of inspection is performed, and what specifically needs to be done. This limitation is due to limited information on the operation, as well as a time limit on the thesis. In the future a more comprehensive model could be created, that takes into account various types of inspections and operations that might need to be performed.

The different functions have been given different colors to classify who the function belongs to, and have different color on the inside based on whether they are foreground or background functions. The colors have the following explanations;

- Grey: Background function
- White: Foreground functions
- Blue: The function belongs to the oil company
- Green: The function belongs to the contractor
- Purple: The function is performed in collaboration

Of the 20 functions identified, four are background functions and the remaining sixteen are foreground functions. The function and their associated aspects have been described in a table, that can be seen in appendix J.

An analysis in the FRAM model is based on an instantiation of the model. In the thesis, the instantiation chosen is the performance of an inspection under normal conditions, where there a team at the oil company plans the operation, before an operator at the contractors performs the operation, under supervision and guidance from experts from the oil company as explained in the case description. Figure 4.4 shows the links created between the functions as a result of the instantiation. As the model is limited, the instantiation includes all of the functions. If the model is expanded further, an instantiation could include just some of the functions for the given scenarios. An analysis based on this instantation can be seen in table 4.4. Variabilities for the different functions have been identified. The focus is on the variability of the output of functions. The function can vary in itself, but not all variability leads to variation in output. If the output varies, this would affect other functions. There are three different ways in which the output could vary. Internal variability is variability of the function itself, external variability is due to conditions surrounding the function, and upstream-downstream variability is related to variability of functions upstream or downstream in the operational sequence (Hollnagel et al., 2014). The functions have been defined according to the categories; human, technology or organization. It also developed an understanding of how the variabilities might interact with eachother.

The FRAM model uses some assumptions regarding the variability, explained in 3.1.4. The assumptions imply that technology already is considered to have some degree of resilience, as it is assumed that variability is known, and not very frequent. In table 4.4, the variabilities of the technology functions have been considered, as they could still occur. Variabilities are added for the foreground functions only.

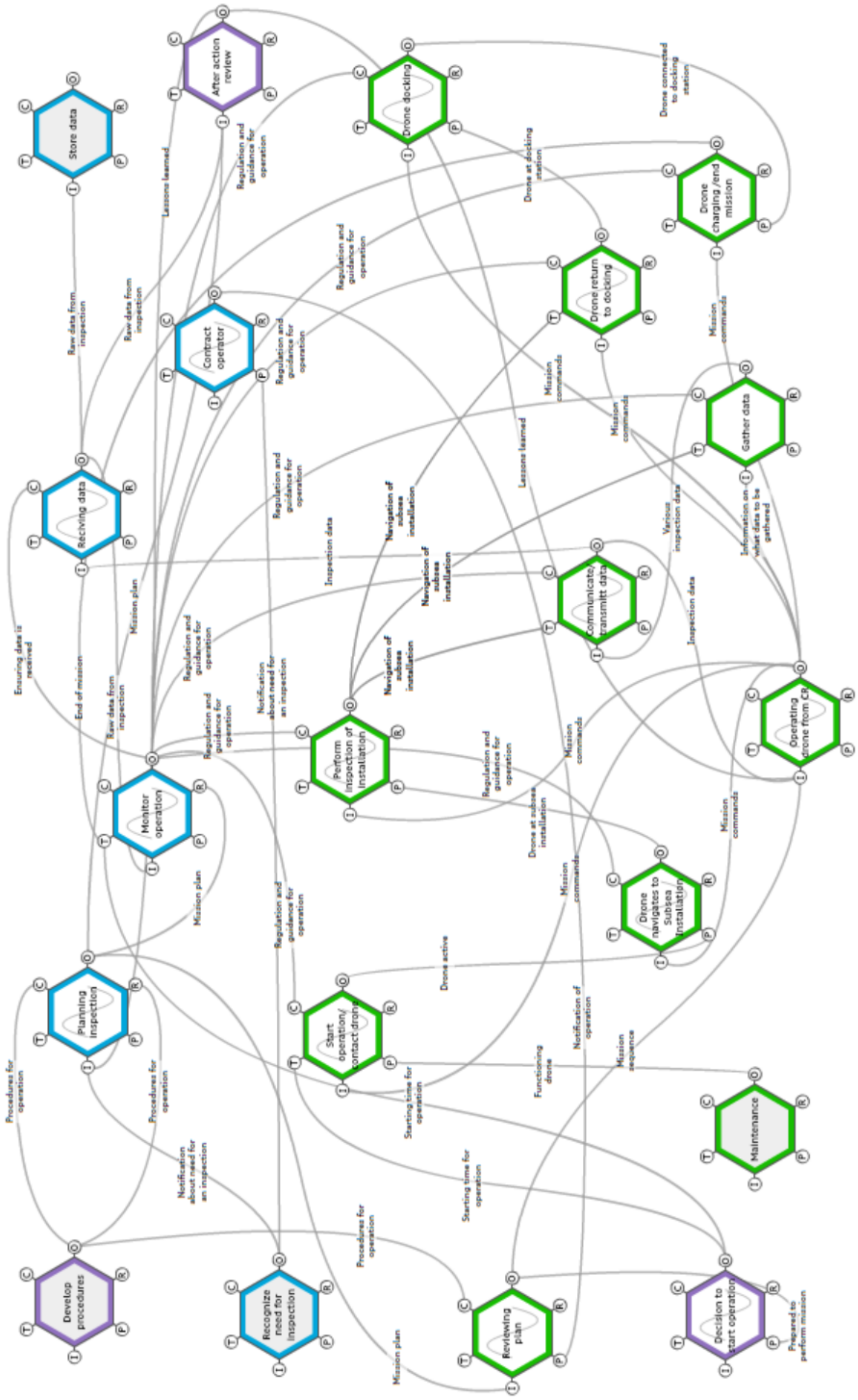

Figure 4.4: The FRAM model for the operation

Table 4.4: Variabilities in the FRAM model

Function	Internal variabilities	External variabilities	Upstream-downstream variabilities
Planning Inspection: Organizational	As shown in the pentagon analysis many factors affect the organization and its performance. For the planning, communication between the personnel involved in the planning, roles and responsibilities of the involved personnel, the organizational culture and the organizations ability to learn from previous experiences are important factors that could affect the quality of the plan. The quality would also be affected if input data used to develop the plan is poor. There could also be delays in the development of the plan if disagreements or conflicts occur, or data to base the plan on are missing.	The most significant external factors for organizations are related to the environment they operate within. Availability of the resources required to perform the planning and expectations from stakeholders could affect the planning.	The only output linked to aspects of this function is the background function (Develop procedures). The procedures are a resource for the development of the plan, as well as a control element. Procedures that are not updated could cause the same mistakes to be implemented in the plan everytime. Proceudres should therefore be kept up to date, and be changed when new experiences dictates it.
Monitoring operation: Human	The operation is monitored by a personnel from the oil company. The performance of this person could be affected by both physiological and psychological factors. Fatigue and stress could cause the person to miss mistakes made in the operation. It could also affect their ability to provide guidance if necessary. This could lead to messages not delivered, or providing information of poor quality. The skill andtraining of the person is also important.	Social factors and organizational factors can affect the performance of the person. Expectations set by the organization could lead to the person being less focused as they have other tasks that needs focus, lacking in the necessary resources (technology) to perform the monitoring. It could also be social norms related to monitoring the operator, where some things are overlooked.	This function depends on data from the operation and control room, in order for the supervisor to see what is happening in real time. The data from the operation therefor must be received by the oil company. This could vary do to poor communication networks, or errors in sensors. This function is present as a control for the operation. It is ment to have a positive effect, and reduce variablities in the operation. Variabilities that occur in the operation will not be caused by mistakes in the monitoring, but can be aided and corrected if the monitoring is effective.
Contacting operator: Human	The operator has to be contacted and notified that an inspection is desired. This is done by the person in charge of communication with the contractor. This is a fairly easy task, but could be delayed do to omission of the activity due to the person being stressed, overworked or having other priorities.	The social relation to the operators might affect how the communication goes. The resources needed to contact the operator also has to function (email, video call or phone). The communication between the parties is not complicated, and should not lead to misunderstandings.	A precondition for contacting the operator is that there is a notice of need for inspection. The notice could be delayed, or the need not discovered, meaning the contacting of the operator would be more critical is the operation is needed as soon as possible.
Receiving data: Technology	Data from the operation has to be transferred from the drone and the control room of the operator to the servers of the oil company. There could be an error in the servers. This could lead to receiving the data with a delay, or not receiving it at all.	There is a possibility for misuse in form of jamming of the network, or hacking the servers in an attempt to intercept and steal data. This could cause data to be lost.	In order to receive the data they have to be transmitted over some form of communication network. Errors in the network and the stability of it could cause data to be delayed or lost. There also has to be data to receive, so the sensors need to record data to be transmitted. Monitoring the data and the servers could helps reduce the variability of this function.
Reviewing plan: Human	It is important that the plan from the oil company is understood. It maps out the scope of the mission, and what tasks needs to be performed. The operator who reviews the plan could be stressed or overworked, missing out important parts of the plan. The skills and knowledge of the person is also important in order to understand all the details of the plan. Also if there is a time factor, the plan might not be read thoroughly, and the operator might conclude that they already are familiar with this type of mission, and therefor it is unnecessary to spend time on it.	Support and training the operator has been given could affect how they go about reviewing the plan. Expectations from both contractor organization, but also the oil company will affect how the operator reviews the plan.	The quality of the plan is important for the operator to be able to read and understand it. If mistakes are made in the planning faze, these would affect the operator as he would have been given erroneous information in the first place. The operator should also keep standard procedures in mind as they work as a control on how they are supposed to perform a mission. Even if something from the procedure is not mentioned in the plan, they cannot deviate from it.

Function	Internal variabilities	External variabilities	Upstream-downstream variabilities
Start operation/ contact drone: Technology	The drone in itself must function. Mechanical errors to components could entail that the drone does not function when contacted.	The drone must be sufficiently charged when the operation starts. There could have been unschedueld use of the drone that causes it to be unavilable, or that the battery is low. Maintenance must be performed on the drone with good skill, and good parts. Poor maintenance or lack of maintenance could mean the state of the drone is not good. Misuse in the form of someone hacking the drone could also occur.	Commands from the operator needs to reach the drone in order to activate it. If the communication network is unstable or not functioning, the operation might be delayed or have to be postponed. Monitoring performed by the oil company contributes to the operation being performed with less variabilities. Maintenance must be carried out to ensure the state of the drone is up to standard.
Drone navigates to subsea installation: Technology	The drone must function. Navigation equipment and propulsion has to function . If the navigational equipment experiences deviations the drone might end up navigating of course. Error in the propulsion could cause delays if the speed is lower than normal, accidents at sudden high speeds, and is it does not function at all, the mission can not be performed.	Maintenance must be performed on the drone with good skill, and good parts. Poor maintenance or lack of maintenance could mean the state of the drone is not good. Incorrect use of the drone could have caused damage to critical components that affect the performance of the drone.	Commands from the operator needs to reach the drone in order for it to navigate to the correct location. Delay of input due to communication network would lead to a delay in the operation. Error in the commands could cause the drone to navigate to the wrong area or cause accidents. If the drone does not respond in the first place, navigation would not be possible.
Perform inspection of installation: Technology	The drone must function. Navigation equipment and propulsion has to function . If the navigational equipment experiences deviations the drone might end up navigating of course. Error in the propulsion could cause delays if the speed is lower than normal, accidents at sudden high speeds, and is it does not function at all, the mission can not be performed. Variabilities are more critical for this function, as it is navigating critical components of the subsea installation.	Maintenance must be performed on the drone with good skill, and good parts. Poor maintenance or lack of maintenance could mean the state of the drone is not good. Incorrect use of the drone could have caused damage to critical components that affect the performance of the drone. Misuse in the form of someone hacking the drone could also occur.	Commands from the operator needs to reach the drone in order for it to navigate to the installation in a safe way. Delay of input due to communication network would lead to a delay in the operation. Error in the commands could cause the drone to navigate to the wrong area or cause accidents. Monitoring by the oil company is ment to reduce the variability of the function.
Gather data: Technology	To gather data, a range of sensors on the drone are utilized. Errors might occur in the sensor causing it to not function, or function irregularly. This could cause gaps in data, or no data at all.	Maintenance has to be performed on sensors to ensure they function as desired. Poor maintenance could result in irregular or no function of the sensors. The gathering of data could also be affected by external factors like visibility. If the sensor is not able to ”see”, the data gathered could be useless.	Commands from the operator needs to reach the drone to activate the necessary sensors and clarify what data are needed. Delay of input due to communication network would lead to a delay in the data gathering. Error in the commands could cause the wrong data to be collected, or missing some or all of the data that was requested .
Communicate/ transmit data: Technology	The data gathered has to be communicated to the oil company, as well as back to the operator (real time data from operation). Delays in the communication network could cause delays in the operation if the real time data are needed to perform the tasks (video). Errors in the communication of data could cause accidents.	Communication could be disturbed by external factors like weather and sea conditions that affect the network. There could also be misuse of the network, someone jamming the signal or hacking in to disturb or redirect communication.	To communicate data there needs to be input data from the sensors. A variability in the gathering of data could mean there is data to transmit. Communication of data needs to happen in parallel with other activities as the data are needed for the operator to know what he is doing.
Drone return to docking: Technology	The drone must function. Navigation equipment and propulsion has to function . If the navigational equipment experiences deviations the drone might end up navigating of course. Error in the propulsion could cause delays if the speed is lower than normal, accidents at sudden high speeds, and is it stops functioning the drone is stuck somewhere between the installation and the docking, and needs to be retrieved.	Maintenance must be performed on the drone with good skill, and good parts. Poor maintenance or lack of maintenance could mean the state of the drone is not good. Incorrect use of the drone could have caused damage to critical components that affect the performance of the drone. Misuse in the form of someone hacking the drone could also occur.	Commands from the operator needs to reach the drone in order for it to navigate back to the docking station. Delay of input due to communication network would lead to a delay in the operation. As the inspection is already performed, this delay would not affect the inspection much. Error in the commands could cause the drone to navigate to the wrong area or cause accidents. If the drone does not respond, navigation would not be possible.

Function	Internal variabilities	External variabilities	Upstream-downstream variabilities
Drone docking: Technology	Docking the drone is crucial to ensure good connection so the drone is able to charge. The drone must function in order to connect to the docking station. Propulsion and navigation must function.	The docking could be affected by sea condition. If the visibility is poor it would be difficult to maneuver the drone into the correct spot. Sea conditions like currents could also affect the connection. Maintenance needs to be performed on the docking station to ensure its function. The docking station has to be available. If another drone has taken the space, docking will not be possible.	The drone must be present at the docking station to be able to connect. If the navigation back from the inspection did not go as planned, the drone will be docked later than planned, or not at all. If the delay is too big, or the drone does not return, the drone might run out of power. It would then have to be retrieved, and brought back. Commands from the operator needs to reach the drone in order for it to perform the docking correctly. Delay of input due to communication network would lead to a delay in the docking. Error in commands could lead to incorrect or no docking. The drone might not charge, and would run out of power.
Drone charging - end mission: Technology	Docking station connection has to function in order for the drone to charge. Also the power supply to the docking station must function.	Weather and sea conditions could affect the availability of power to the docking station. Maintenance of the docking station helps ensure that charging is functioning at a desired level.	The drone could be not connected, or not properly connected to the docking station. This would cause the drone to charge with lower efficiency, or not at all. Commands from operator are necessary to end the mission, and put the drone back to "sleep". Communication network delays or errors could cause the drone to stay active, putting extra unnecessary strain on it.
Operating drone from control room: Human	This is a critical part of the operation. The operator has to stay alert, and might be required to command the drone to perform tasks in close proximity to critical components and systems. Errors due to fatigue, stress, workload and sleepiness could all affect decisions made by the operator. Factors like these could cause the operator to make errors that could cause accidents involving the drone. Cognitive abilities and decision making based on input data is are also factors that can vary.	Resources like the control room setup, software for the control of the drone, and operational training can all cause variabilities. Good training can reduce the amount of human errors, and thus give less variability in the operators performance. The control room setup, if designed right can make performing the missions easirer. If the setup is difficult to use and the software difficult to navigate, variabilities could occur. If these aids dont function, the mission can not be performed. There are also organizational impacts on the operator, both from own organization and the oil company. Expectations from the oil company could vary from the ones from the contractor, causing a conflict of what expectations to live up to. Who has the authority, as well as the division of roles and responsibilities, also has an impact.	Understanding of the mission plan is important for the operator to make the correct decisions. If there are misunderstandings, or the operator omitted something in their review of the plan, errors and deviations from the plan could occur.
Decision to start operation: Organizational	Communication and collaboration is necessary between the oil company and the contractor. Roles and responsibilities in relation to the operation affects how the decision will be reached. Authority also affects who makes the decision, and what weight different opinions are given.	It has to be assured that there are not any other operations in the area of the inspection, to ensure there will be no conflicts. The drone that is needed, and the operator, also have to be available at the time of the operation.	Based on the mission plan and scope the estimated time of the operation is given. This can be seen as input for decision of when the operation is performed. Having a plan, and reviewing it is such a precondition for deciding when to perform the mission.
After work review: Organizational	The organizations ability to learn. Transferring tacit knowledge (experiences) to explicit knowledge (recording it in procedures and plans).	Inter-organizational communication and collaboration to ensure that the lessons learned are applied.	To perform the after work review the plan should be used as input so that WAI can be compared to WAD. The data from the inspection should also be applied. Both the operator and the person monitoring the operation should be part of the after work review. This function, if performed correctly, should contribute to learning and improving in the operation. As such it should contribute to improving resilience, and supporting the achievement of successful operation.

Results in the context of the DRMGs

FRAM allows for identifying potential variabilities in activities. When these are known, it is possible to see how they affect the system, both in positive and negative ways. It also show how the same variability could have very different consequences. Two situations with different outcomes could still have similar underlying causes (Hollnagel et al., 2014).

The model identifies variabilities or combinations related to human, technology and organizational factors. It also shows that variabilities might propagate, and have consequences for other functions. The variabilities that are most common, and affect the operation the most are human and technical factors and the interaction between them. This is mainly related to the drone operator and the drone in itself.

The FRAM model shows possible variabilities in the operation related to human, organizational and technological functions. The model shows how the variabilities could have positive or negative effect on the systems resilience, and also considers how variability in one function affects another. These variabilities could be considered as sources of resilience or brittleness in the operation. The FRAM shows that it is of interest to identify these in order to reduce, or strengthen the effects, and as such improve the resilience. This can be done through applying the triggering questions from the *identifying sources of resilience* and *Noticing brittleness* capability cards.

The model has also been used to show what actors are involved with the various functions. The roles and responsibilities of the different actors could change if different contract models are applied, or if unexpected events initiates a need for changes. This could be further explored through triggering questions from the *sharing information on roles and responsibilities* capability cards. Questions of coordination, how the organizations affect each other and the ability to adapt and reorganize could be of interest.

4.1.4 Literature Review

Here the findings from the analysis of the final set of papers in the literature search is presented. The analysis focuses on five categories. These were selected based on the research questions, and keywords from the abstracts of the papers. The categories are;

1. Opportunities
2. Challenges
3. Communication
4. Charging/Docking
5. Mission Planning

The papers analyzed represent use of different types of drones (mobile robots) in different industries, as well as some papers that focus on drone operations in general. The three main type of drones considered by the papers are land based drones, aerial drones and underwater drones. The findings within the different categories considered, as well as their implication regarding resilience of the operation, will be summarized consecutively.

Visualization of main results

Figure 4.5, 4.6 and 4.7 show a the main results from the literature review related to the drone type considered by the different papers. The figures are divided into the five categories of the review, and shows the most important challenges, opportunities and solutions found for the categories. There are some main differences between the different drones. One of the main differences is for communication. For underwater drones, communication is generally a bigger challenge than the land based and aerial drones. Solutions for communications are less stable, and require further development. Another difference is that charging underwater is more challenging due to the marine environment which causes disturbances and misalignment's in docking stations.

All the drones represent similar opportunities, in performing work that is difficult or hazardous for human operators, saving costs and gathering data for better understanding and learning to improve the operation. Battery life is the most mentioned challenge, and is common for all types of drones. Different solutions to deal with this including use of multiple vehicles, multiple charging stations and optimal mission planning is applicable to all types of drones. The findings within the different categories are further described in the following sections.

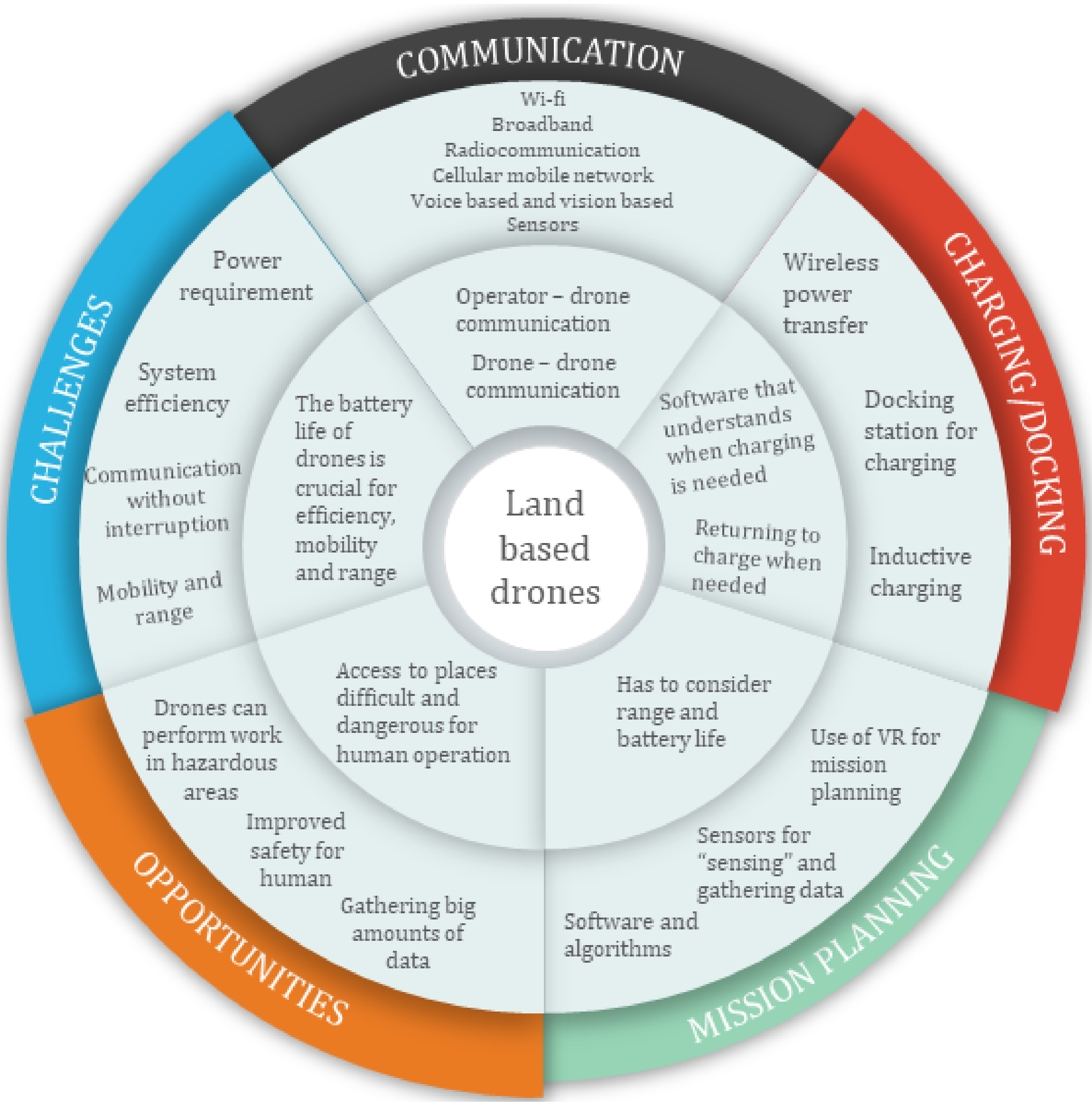

Figure 4.5: Visualization of results for land based drones

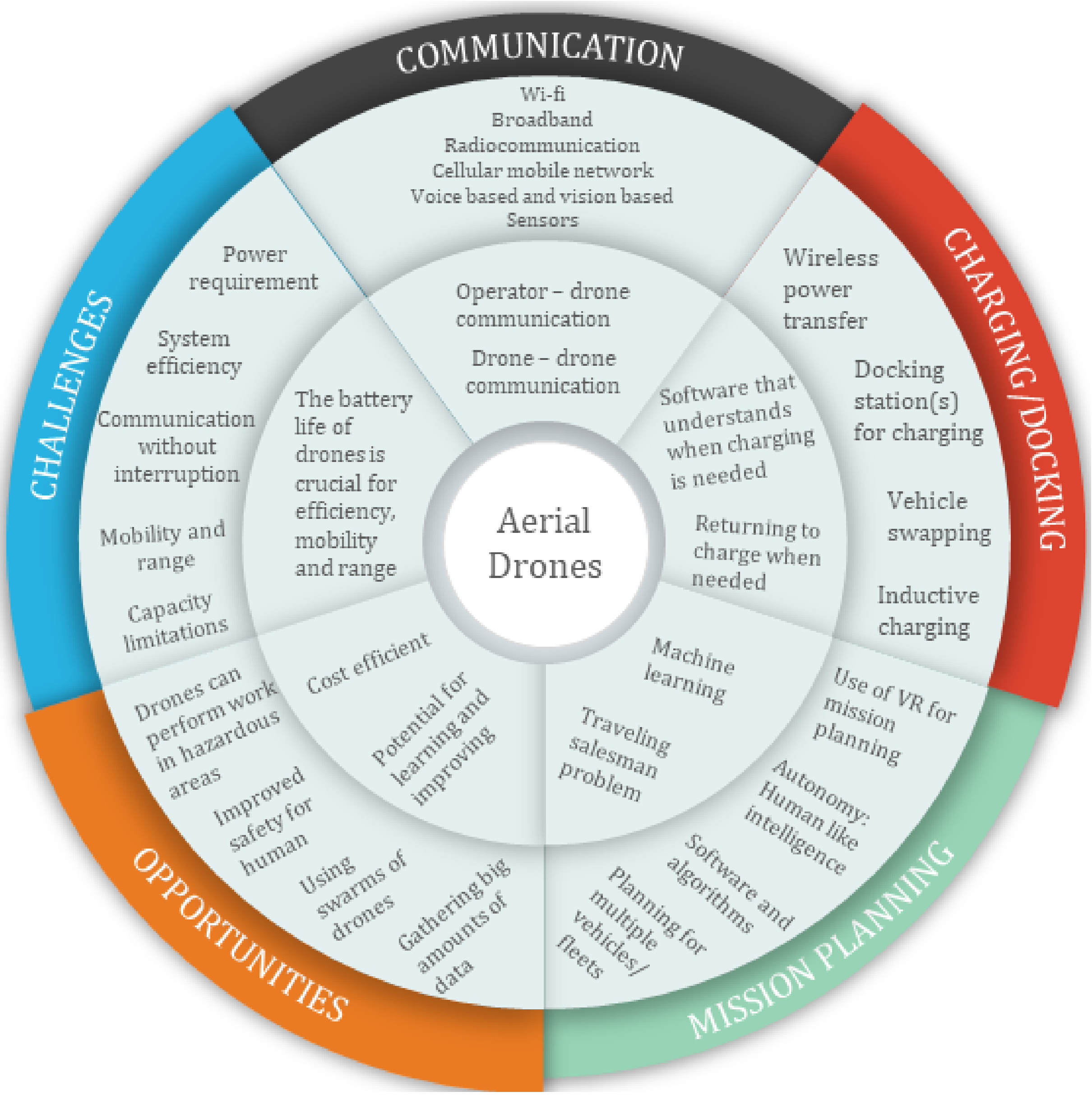

Figure 4.6: Visualization of results for aerial drones

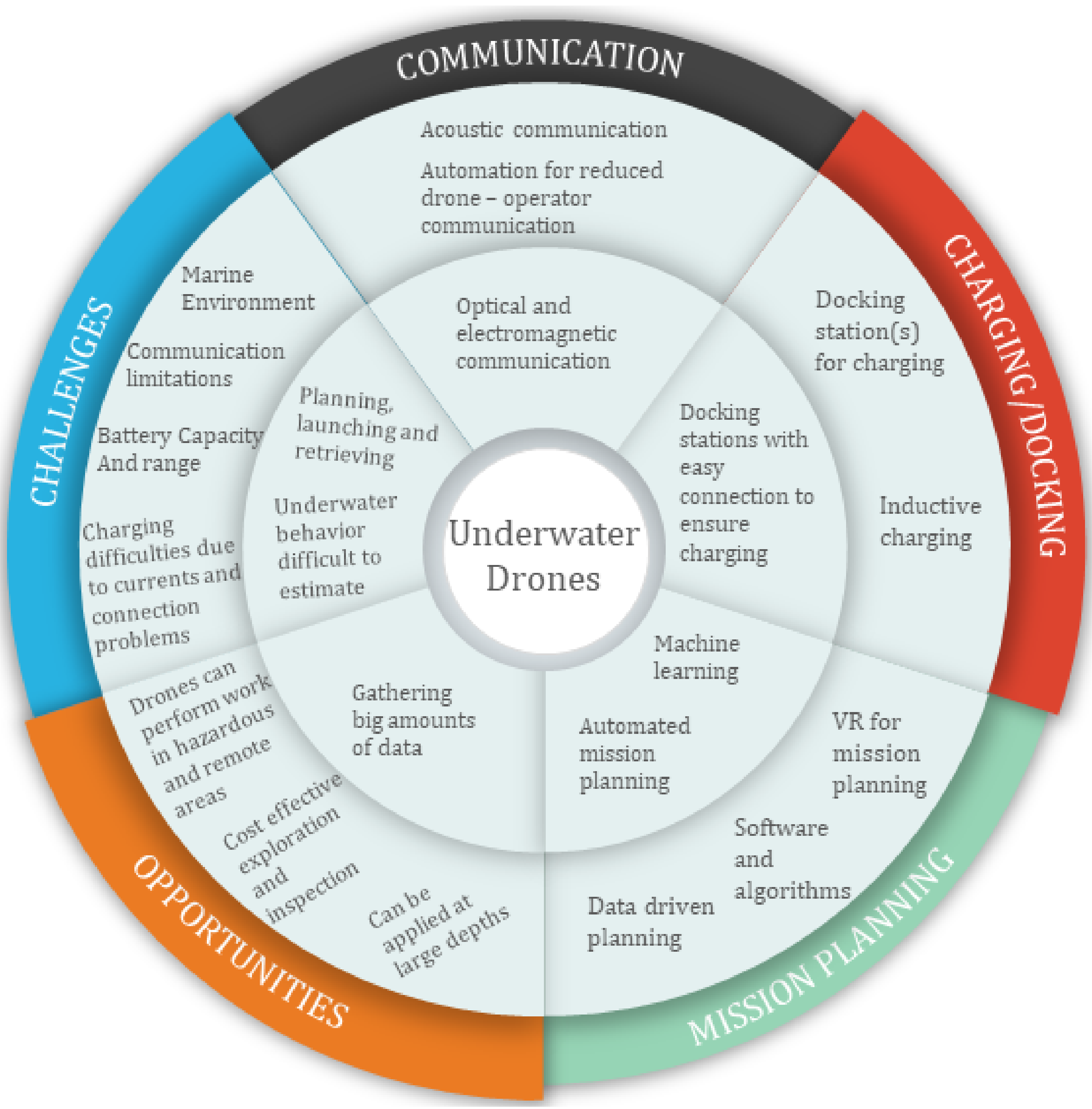

Figure 4.7: Visualization of results for underwater drones

Opportunities

The use of drones for various operations pose a variation of opportunities and benefits in a wide range of industries. This is whether you use the drone for operations on land, in the air or under water. The papers identify many different opportunities for use of drones.

One of the opportunities that is mentioned by different papers is that drones have the ability to perform tasks in remote locations, and tasks that are considered hazardous. Williams and Yakimenko (2018) considers a drone as a tool to help give the operator (military) a way to "access hazardous environments, work at small scales, or react at speeds and scales beyond human capability". Cheah et al. (2019) state that drones could be applied for inspections and interventions in hazardous environments in various industries like nuclear plants, offshore wind turbines, oil and gas platforms, offshore substations,underground mining tunnels, underwater pipes and more. This covers use of both land based, aerial and underwater drones. Using drones for hazardous operations will ensure the safety of human operators, as they will be separated from the hazard. Atyabi et al. (2018) and Homma et al. (2017) also considers a benefit of drone operations to be the possibility of performing hazardous tasks at remote locations. Homma et al. (2017) considers use of aerial drones to inspect power lines. The power lines stretch over large areas, and can be difficult to access. In addition, work close to the power lines would be considered hazardous for a human operator. Use of drones solves both these problems, and can perform the inspection more efficiently.

Another opportunity of using drones is reducing costs. Atyabi et al. (2018) point out that underwater drones can perform spend longer time on missions, and perform them more cost efficiently. As compared to use of divers for underwater missions, the reduction in costs for the operation would be significant. The article also mentions cost reduction as one of the benefits of using aerial drones. Kim and Moon (2018) mentions that using aerial drone for delivery would save labor costs. The more autonomous the drones are, the less human interactions are needed. This saves costs related to operators.

Drones have the potential to gather large amounts of data if they are fit with the right sensors. This data creates an opportunity. In the face of the development of technology and methods big data, internet of things and progressive use of automation, gathering large amounts of data is necessary. the data can be applied for a better understanding of the drones in themselves, but also of the bigger system surrounding the drones and the environment they exist in. Machine learning and use of artificial intelligence is also gaining popularity, and is dependent on the data gathered. Atyabi et al. (2018) mentions that the ideal drones should not rely on human inputs, but learn and make decisions based on data gathered. Sayed et al. (2018) suggest a sensor platform for drones, and show how the drones could be fitted with a big range of sensors, and how data from the drone sensors could be combined with other sensor data.

The opportunities would also pose implications for the resilience of the operation. The impact with most potential would come from the gathering of large amount of data. All this data would be a big contributor to the ability to learn from experiences in the operations. As described in section 2.6.1, Hollnagel identifies the ability to learn as a cornerstone of resilience. Learning from what goes well is also a focus in the DRMGs. In the CC *Assessing resilience*, one of the topics is *Identifying sources of resilience: learning from what goes well*. As described in section 2.8.3, this topic focuses on learning from success in everyday performance and successful operation. While gathering big amounts of data gives the opportunity for such learning, systems and expertise that has the capability of making sense of and applying the data for this purpose has to be present .

Use of drones to perform hazardous and remotely located tasks can also impact the resilience. Removing the human from the hazard will reduce the stressors on the human operator. The drone cannot feel fear or stress in hazardous situation. The human operator has less pressure on their back when the drones are performing the hazardous tasks, as the consequences of mistakes will be smaller. This will increase the system ability to respond in unexpected events, and increase its robustness. The system will also have an increased capability to rebound after disturbances.

Challenges

The papers that were found, show an assortment of challenges related to drone operations. The challenges vary slightly for the different type of drones, but they have some challenges in common.

The most represented challenge in the papers is the power requirements and battery life problem. The size of the drones does not allow for big batteries or engines, and this limits the battery life of the drone. This will affect the range of the drone and causes downtime in operations, making the operations less efficient. This challenge is present for all the different types of drones. (Williams and Yakimenko, 2018),(Kim and Moon, 2018),(Haibing et al., 2018),(Cheah et al., 2019),(Atyabi et al., 2018), (Lohan et al., 2018)

Another challenge that is recurring, is communication limitations. Both drone to drone communication and drone to operator communication is considered in the papers. It is considered a challenge for all the different type of drones, but the nature of the challenge is slightly different. For land based and aerial drones communication challenges are linked to unstable networks, frequencies and areas with varying signal/connection, as well as hacking and spoofing vulnerability of the communication connection. For underwater drones the communication challenge is mainly that wireless communication underwater is difficult, and the solutions that exists today are much less stable than those for land or aerial drones. (Lohan et al., 2018), (Arteaga et al., 2019), (Jarchlo et al., 2016), (Atyabi et al., 2018), (Thompson and Guihen, 2019)

The battery life challenge will affect the availability of drones. It also affects the capacity, as more demanding tasks often require more power. The drone could adapt to lower power levels by using the leftover power to get back to a charging station, but would have to stop the tasks at hand. Low battery is a problem that can easily be anticipated. When planning missions, battery life has to be taken into account to avoid the drone running out of power while in operation. The communication challenge also impacts the resilience, and is further discussed under the communication category.

Communication

As mentioned, communication is considered a challenge for drone operations both on land, air and underwater. The papers suggest various solutions for solving the communication problem in different mediums.

Many of the papers talk about use of wifi or mobile network to communicate, and radio communication (Homma et al., 2017), (Atyabi et al., 2018), (Williams and Yakimenko, 2018), (Lohan et al., 2018), (Jarchlo et al., 2016). A challenge with using network could be that the drone activity could cause an increase in channel congestion, and produce unpredictable response times. With the rise of Industry 4.0, and new concepts like the *Internet of things*, more and more gadgets and technology will be connected to networks. Lohan et al. (2018) suggest that the drones should be able to communicate on the conventional frequency networks, they should also be able to utilize high frequency networks. The new 5G systems integrate the conventional frequencies with high frequencies to improve the network (Lohan et al., 2018).

Another problem with the network communication is that drones move around, and this may cause communication paths to change. Radio wave propagation is also vulnerable in some environments, and you can experience areas where there is not network coverage (Jarchlo et al., 2016). (Jarchlo et al., 2016) consideres adding mesh capabilities to the drones. A mesh network allows routing of data in a network of devices. It works the same way as antennas for transmitting data to mobiles, but takes into account that routers can be moved around. By adding mesh capabilities to the drones, they can connect to each other. Mesh networks will automatically find the best way to maintain data flow between two different points. If a router fails, the network should find a new route by itself (Jarchlo et al., 2016).

Another issue to consider regarding communication is the human-drone communication. With an increased use of drones it is important that the human operators can collaborate with them in a good way. Maurtua et al. (2017) looks at using *natural* communication between the drone and human. This entails an environment where interactions happen naturally, through voice and gesture based communication (Maurtua et al., 2017).

The various challenges related to communication for the drones, will impact the resilience. As shown by the pentagon analysis in section 4.1.2 and 4.1.3 communication loss or delay could possibly occur. Delay or loss of communication would affect the ability to respond to both expected and unexpected situations as long as the drone is dependent on commands from an operator. Another thing to consider is how the drone responds to the event of loosing communication in itself. To ensure good resilience of the system, it should be able to rebound from the disturbance, or adapt to it.

There is also a potential for the drones to learn. If there are areas or operation modes that makes communication more vulnerable, this information could be stored and used to improve by finding alternative routes or working methods to avoid the loss of communication. This would again aid the drone in its ability to anticipate possible loss of communication, or to exploit areas where the communication is good.

Human drone communication will also impact the resilience of the operation. As explained in 2.4, the integration of humans and complex systems require good design of the system, and sets requirements to the operators understanding of the system. Flaws in human machine communication could lead to wrong or no action taken. This impacts the systems ability to respond. There has to be a level of trust between the drone and the operator, trusting that the information given is correct. There also has to be a common understanding of the operation and the external conditions encountered. To avoid misunderstandings or communication errors, the interaction should be made as simple as possible. There is also an arena for learning and improving the communication through experiences from performed operations. A possibility for this could be the use of VR for mission planning, which is further explained under the mission planning category.

Charging/Docking

Solutions for charging and docking is important to handle the power requirement and battery life challenge. Various solutions are proposed to deal with this. Various papers looks at docking stations for the drones with inductive charging. Haibing et al. (2018) looks at a docking solutions for AUVs with inductive charging. The article highlights how charging can be difficult underwater, as a result of the marine environment. Docking errors and ocean currents lead to gaps and misalignment to the charging couplers (Haibing et al., 2018). As a solution it is suggested to have a docking station that hinders movement of the AUV, and ensures good contact points for charging. Cheah et al. (2019) looks at different ways of wireless charging. Inductive charging is one of the methods discussed. Inductive charging is seen as a matured technology, and is widely used, but application for drones and mobile robots is more limited. Use of inductive floor mats is an example of a way for charging. They also point out that for underwater drones and robots, guide and locking mechanisms have been used to hold the drone in place and ensure sufficient charging (Cheah et al., 2019). Cheah et al. (2019) also consideres other solutions for wireless charging like acoustic charging, magnetic resonance and capacitive charging.

Another way of ensuring that the drones have sufficient battery life, and can cover larger range, is the use of multiple charging stations or multiple drones. Kim and Moon (2018) suggest drone stations distributed around a distribution center where the drones start. This way, the drones can charge along the way if necessary. The article references use for land based drones, or aerial drones with *drone airports or stations* placed around the areas they operate. Williams and Yakimenko (2018) look at the possibility of vehicle swapping. The vehicles swap in a set location based on monitoring of battery life and management through a ground based control station (Williams and Yakimenko, 2018). Thompson and Guihen (2019) looks at using fleets of AUVs, thus performing work more efficiently. This way each vehicle can perform fewer tasks, and this ensures that the battery life is sufficient.

Another issue with charging, is to ensure the drone will return when charging is necessary. Chang et al. (2018) looks at a simple robot vacuum, and mechanisms to ensure that the robot returns to the docking station for charging when necessary. This solution relies on calculating moving distance and rotating angle of the robot, and scanning infrared signals from the docking station with use of camera to find its way back to the docking station (Chang et al., 2018).

As mentioned under the challenges, the problem with battery life could impact the resilience negatively. Finding a good solutions for charging, improving the battery life or using multiple vehicles could help reduce the probability that a mission would be affected by shortage in power supply. Making the drone capable of finding its way back to the docking station could also secure that the drone is not lost in case of loss of communication with the operator. If the drone is programmed to return home when communication is lost, the drone would not be *lost* and need retrieval. This would improve the systems ability to rebound.

When applying multiple vehicle, the different vehicles could function as a sort of backup for each other. This would improve the ability to respond, as if one drone cannot deal with the challenge another might. It also improves the systems allover ability to adapt, as one drone could replace the other if necessary.

Mission Planning

Mission planning is an important part of drone operations, to reduce errors and ensure effective operation. Many things have to be considered during the mission planning, and the papers suggests different approaches.

Mission planning is key to ensure efficiency and safety of the operation. Mission planning also plays an important part in dealing with battery life challenges and other variabilities in operation, as the plan should assure that the drone can perform the tasks it has been given, and return to docking with the battery capacity it has available. Some of the papers suggest algorithms and software (based on statistical and mathematical models) to help with the mission planning. Thompson and Guihen (2019), Homma et al. (2017), and Cavalcante et al. (2017) all look at software and algorithms based on various statistical and analytical models. In addition they depend on data that is gathered by the drones during missions as input. Atyabi et al. (2018) addresses how human machine learning can be applied in mission planning, where the drone itself can make some desicions or react to situations based on previous experiences. Kim and Moon (2018) suggest using the travelling salesman problem for optimal planning of missions.

Liu et al. (2018) suggest using VR technologies for mission planning. By performing missions in VR, users can learn and gain experiences, and can consider aspects of the mission plan like safety, battery time, difficult tasks and more before executing the operation. The process can be recorded, and operators can learn from the run through of the mission in a safe environment with no consequences. Checklists for the operation can be developed based on the VR missions (Liu et al., 2018).

The mission plan is an important tool for successfully performing operations. In mission plans and procedures lies a big potential to learn. *Work as imagined* (WAI) is rarely the same as *work as done* (WAD). This deviations that have a positive effect as well as deviations that have negative effect. When one deviates from the plan or procedure, and the outcome is a more successful operation, the plans and procedures can be updated to include the new knowledge gained through experience.

Through mission plans it is also possible to anticipate possible challenges and deviations might be expected, and thus plan responses for these. It is in that way a good tool to deal with many of the challenges already mentioned. The use of VR for mission planning would be a good tool for learning and monitoring the operation without any consequences. This way one can encounter events that one did not anticipate, and plan for how to respond in the case such an event occurs. It would therefor improve the ability to anticipate and respond to many situations.

4.2 Data Collection and Processing

The interview guide was developed based on the picture formed by the information in section 4.1. The final interview guide can be seen in appendix K. Following the information that was gathered when applying the interview guide is presented. The interviews were focused on two of the six main DRGM themes; *Assessing Resilience* and *Supporting Coordination and Synchronization of Distributed Operations*. The questions were formed by using the triggering questions found in the Capability Cards (CC). A total of six elite interviews of subjects with different positions, and from different departments of the oil company, was conducted - the first five with one interview subject, the last with two together. Being focused on an operation under development, the interviews were focused on the subjects' experience with similar operations, and their view and opinions on the future operation. The interviews were conducted in Norwegian, and although the data material gathered is given in quotations without interpreting, translation has been performed. The purpose of the citations is to provide the reader with a clear understanding of the material, and support the results presented. The data has been sorted based on the subjects' background and subcategories within the DRGM themes so that the views and experience of the subjects' could be compared.

4.2.1 Assessing Resilience

This section is focused on the interview subjects view and experience on the organizations ability to identify the existing sources of resilience and brittleness in the project and its development. Two capability cards are considered within this theme; Identifying sources of resilience and Noticing Brittleness.

I. Identifying Sources of Resilience

This topic was addressed to identify sources of resilience in existing operations with the company, sources that can be applied in the project and the UID operation. This was conducted by an examination of the following abilities;

- **The adaptive capacity:** To what degree does the organization have the ability to adapt to a sudden change in the operation?(DARWIN, 2018b).
- **Resources:** Does the organization have available resources in the operation in case of a change in demand, and coordination of the resources?(DARWIN, 2018b).
- **Monitoring:** Does the organization have the ability to monitor threats and success in the operation? (DARWIN, 2018b).
- **Dependencies and interactions:** Do the company have an understanding of the interconnections in the operation, and of how variations can propagate through the system? (DARWIN, 2018b).
- **Learning:** Does the organization have the ability to learn from what goes well/right in the operation? (DARWIN, 2018b).

The Adaptive Capacity

As mentioned in section 2.6.1, the ability to adjust to future events due to evolving conditions, is one of the four resilience concepts discovered by Woods in his literature study. The organization's adaptive capacity was examined by their ability to prepare and respond to a sudden loss of capacities or increasing workloads in the operation. This by the means of strategies, reorganizing roles and responsibilities, and training. The main findings are presented in the following tables.

As a part of the adaptive capacity, strategies applicable for handling a sudden loss of capacity and/or increase in demands during the remote operation were examined. The key findings are presented in 4.5.

Table 4.5: Identifying sources of resilience: The adaptive capacity I

The adaptive capacity I:Applicable strategies	
Interview subject with background from:	**Findings:**
Development of UID technolgy	*Consider the degree of criticality of the operation under the implementation, to reduce the risk in the startup* *The knowledge we have concerning the operation of ROV and vessels, we can apply, I think* *Built-in algorithms that allow the drones to return to the docking stations if capacity or communication is lost.*
Environment surveillance	*If we lose contact with the drone it should lie down and wait, and send out signals so we can search for it with a ship and pick it up.*
Marine operation and control center	*To make sure that these events don't occur its important to look at all parts of the value chain, and build redundancy where possible or by using systems and parts that are easy to replace. Also, the troubleshooting system should be easy to understand.*
Development of UID	*Search for the drone at the last known location if loss of acoustic contact or communication with the drone* *If you loose contact with the drone it would be natural to contact the operation center.*
UID implementation	*Firstly we might need to send out a vessel that tries to save the drone, and perform the work for the drone.*
Subsea and ROV	*It's three possible alternatives in this situation; The drone return to docking. The drone moves up to the surface, sending out signals to be found. The drone lay down at the seabed, and can be found by the use of a transponder and picked up by a vessel or an ROV.*

One strategy, suggested by the interview subject with background from development of UID technology, is that the technology and solutions are thoroughly tested before they are applied in more critical operations. The subject mentions that risk can be reduced in the beginning by implementing the solutions in less critical operations. This way, experiences can be gathered before applying the solution for critical operations, making the system more robust and adaptive. In the startup phase it is therefor a potential for improving the adaptive capacity by learning through less critical operation with more room for trial and error without severe consequences.

The interview subject with background from marine operation and control center suggested the use of easily interchangeable components in the system. This strategy focus on building redundancy in the system by securing multiple persons with sufficient competence in the system, technical systems that can easily be repaired or changed. A strategy that can improve the potential to respond, adapt and gracefully extend the performance. For example, if an operator find themselves in a situation where they lack the knowledge required, there are other persons in the system that can contribute to closing the knowledge gap. It can also improve the ability to rebound. An example is if technical components in the system fail, there exist a backup or the components can easily be replaced or repaired.

Multiple of the subjects suggest possible strategies related too recovering capacity, pre-decided actions for the drone and how to locate and retrieve the drone if it can not recover capacity. The first strategy should be prioritized to recover the capacity to continue the operation, and is directed towards the ability to rebound and gracefully extensibility. The two other strategies focus on the ability to recover or rebound. These interrupt the operation, but focus on recovering the system.

Further, existing strategies within the company, applicable for handling sudden loss of capacity and/or increase in demands during the remote operation were examined. The key findings are presented in table 4.6.

Table 4.6: Identifying sources of resilience: The adaptive capacity II

The adaptive capacity II: Existing strategies	
Interview subject with background from:	**Findings:**
Development of UID technology	*We have knowledge concerning the operation of ROV that can be applied in the development of the operation, we have knowledge and procedures, knowledge regarding the needed competence in the control room and for operators.*
Marine operation and control center	*We have seen some issues regarding network before. So we need to plan for backups and alternatives for the network and the battery life.*

The subjects highlight that similar operations that apply ROVs, gathered knowledge and competence that can be applied to deal with capacity challenges for the UID operations. Knowledge concerning operation of the ROV, as well as developed procedures, and competence related to control room and operators already exists within the company, or at the suppliers. There is a possibility to learn from these operations, both from successes and challenges they have encountered. The subject from Marine operation and control center specifically mentions the example of communication network and battery life, which have proven to be challenging in existing operations. This is also backed up by the findings of the literature review in section 4.1.4.

As mentioned in 2.6.1, two of the four cornerstones of resilience is the ability to anticipate further development, and the ability to respond. Were the ability to anticipate require to know what to expect, and the ability to respond, to know what to do. These abilities can be challenging when developing a operation with little experience. This can also be illustrated by the following quotation given by the subject with background from development of UDI: *Of course, it is a step in development to pull the operation onshore, and especially when you start to cut this umbilical cord, to make these drones more or less autonomous, then we have little, direct experience with it.*

Next, the company's strategies for reorganizing roles and responsibilities to handle events that deviates from normal where examined. The results are presented in table 4.7.

Table 4.7: Identifying sources of resilience: The adaptive capacity III.

The adaptive capacity III: Reorganization of roles and responsibilities	
Interview subject with background from:	**Findings:**
Development of UID technology	*It is key to have a UID service including specialist expertise. This must be secured through the contract with the suppliers.*
Marine operation and control center	*It is demanding to build a 24/7 support network with people who are competent to fix all elements.* *Easily interchangeable components that the operators can replace is a possibility.*

The subject with background from development of UID technology points out the need of available expertise to handle deviating events. These should be available if it is necessary to reorganize, and for someone to take over roles in the operation. At the same time, the subject from marine operation and control center identified having 24/7 availability as challenging. It was therefor suggested that easily interchangeable components as another coping mechanism, to reduce the need of the expertise. This allows the operators to easier deal with deviations on their own, and reorganization of roles would not be necessary.

As the supplier performs the operation, it has to be ensured that the necessary competence exists within the supplier organization. The subject with background from development of UID technology points out that this competency should be secured through the contracts with the suppliers. Being able to reorganize is an important part of making the operation as adaptive as possible. The oil company applies integrated operations, as described in section 2.3 This would require some coordination between the oil company and the supplier, which is addressed later in the section.

Lastly, for the adaptive capacity, the personnel's exposure to unexpected events and variations as part of their training were examined. The findings is presented in table 4.8.

Table 4.8: Identifying sources of resilience: The adaptive capacity IV

The adaptive capacity IV: Training for variation and unexpected events	
Interview subject with background from:	**Findings:**
Development of UID technology	*We use the concept of familiarization. So, one thing is that you ensure that you, that those who are going to perform the job must have a basic competence and basic training. But then, when you want to do special types of new assignments, we familiarize the team going through that operation.*
Environment surveillance	*Yes, I think it must be a scenario to prepare for. Now I shouldn't say it's a high probability, but it's not an unthinkable scenario. So you have to have a plan and a strategy for that.*
Marine operation and control center	*It is not possible with a 24/7 support network, so that they can understand and fix the error, find alternative work methods, or find alternative ways to solve it, is important.*
Development of UID	*I think that becomes just as essential a part of their education as it is today. But, it is hard to predict all types of scenarios, so many things have to be improvised.*
Subsea and ROV	*They must be able to handle such situations, such as losing communication or not knowing where the drone is. Then the personnel must be trained and know exactly what to do.*

As presented in table 4.8 the subjects agree on the importance of be able to handle situations as they happen. Being trained to deal with various situations that could occur, improves the ability to adapt to changes, and rebound from events. Experiences from operations could be applied to the training as a way of transferring knowledge. The subject with background from development of UID technology mention the use of familiarization to ensure basic competence and training. Familiarization is defined as *the accumulation or skill that results from direct participation in events or activities* (The American Heritage Dictionary, 2020). But, as pointed out by the subject from development of UID, it is hard to predict all types of scenarios, and therefor what situations to prepare for.

Resources

This section address the company's ability to facilitate for available resources, and coordinate these. The key findings are presented in table 4.9 and 4.10.

In table 4.9, the availability and facilitation of resources is considered. It presents subjects opinions on what additional resources and work methods might be available for the operation.

Table 4.9: Identifying sources of resilience: Resources I

Resources I: Availability and facilitation of additional resources and work methods	
Interview subject with background from:	**Findings:**
Development of UID technolgy	*We are a large company with many expertise environments. And we need to find an operating model for how to cooperate internally in the company.*
Development of UID	*It will be a bit of trial and error in the beginning, as there are always new issues.*
UID implementation	*Should be able to rely on conventional backup during the transition phase.*
Subsea and ROV	*There must be someone accompanying the operation, knowledgeable people, 24 hours a day.*

The interview subjects from the development of UID technology and development of UID, points out that the availability and facilitation of resources and work methods will require some trial and error in the beginning when developing an operation model. The UID implementation subject said that the company should be able to rely on conventional backup during this transitioning phase. The subjects from subsea and ROV said that there should be someone competent that can accompany the operation 24 hours a day, a solution previously pointed out as impossible by the subject from marine operation and control center in table 4.8. Being able to facilitate the sufficient resources for the operation helps make the operation more robust to variabilities. If resources are not available, it could make the operation less adaptable and affect its ability to rebound.

Table 4.10 considers how the additional resources and work methods are coordinated between the actors in the operation.

Table 4.10: Identification of sources of resilience: Resources II

Resources II: Coordination between actors when in need of extra resources.	
Interview subject with background from:	**Findings:**
Development of UID technology	*Then I think we use something called integrated teams, that we work very close together then. Whether we sit physically in their control room and participate in the operation and provide guidance along the way, or if you sit on a slave screen in the company's office, it can be both, but that we sit very close and have very close cooperation, much closer than today.*
UID implementation	*We currently have some fields where we have ROV services. And for example, when a vessel arrives on the field, there are ROV operators from another company operating the drones. So really, it's not going to be anything new for us.*
Subsea and ROV	*The coordination will be performed like our existing operations. The company needs to develop a procedure, approved both by us and the operational part. We have a work permit system, where this needs to be incorporated just like our other operations. So there is nothing new for us, we keep following what we already have.*

As presented in table 4.8, the findings indicate conflicting views on to what degree the UID operation will be affected by the coordination between actors. The interview subject from the development of UID technology considers the need for much closer cooperation than today. This involves applying integrated teams, where representatives from the oil company could be physically present in the control room, follow the operation on a slave screen from their own offices, or both. Close coordination of the operations like this allows the oil company to provide guidance during the operation, and backup in case it is needed. It also ensures that the actors work close to develop the operation with shared experiences and knowledge. In the FRAM analysis in section 4.1.3, the oil company following up the operations like this is identified as a possible way to reduce variabilities in the operation, and as such improve the resilience.
Both the interview subjects from UID implementation and subsea and ROV, however, do not think that the coordination between the actors will differ from the existing ROV operation. This involves the oil company being responsible for developing procedures and work programs, and the operators performing the operation on the installations. There is also a work permit system to ensure that the contractors have the permits to perform the operation before starting. In this scenario the contractor would have to ensure the necessary extra resources on their own.

Monitoring

Another source of resilience is the ability to monitor threats and opportunities in the operation. The findings from the examination of the company's expected ability to monitor the operation, and the ability to learn from it, is presented in table 4.11.

Table 4.11: Identifying of sources of resilience: Monitoring

Monitoring	
Interview subject with background from:	**Findings:**
Development of UID technology	*We've gotten better and better at this. One part is to have access to a lot of data, but then the useful information needs to be extracted from that data.*
Marine operation and control center	*With algorithms directed at what to look for, it can be almost self-repairing. Of course, mechanical things are difficult. But it is quite possible to be notified a little before mechanical issues happen so that it can get back into place and be fixed. But there are a considerable amount of software adjustments in such a package, and here it is quite possible to have machine learning to adjust itself, update itself, get changes.*
Development of UID	*I expect that machine learning will also be used for underwater drones in the future. That when you have performed a task, you have machine learning that memorizes it, and the next time you wish to conduct the same task, it is only to press a button.*
UID implementation	*Initially, we will have human-controlled drones. But the ambition in the long run, on a time horizon of maybe five or ten years, is that you use machine learning. And that the drone should use its algorithms for the choice between installations etc.*
Subsea and ROV	*Machine learning for the drone may be an example. Yes, because if the drone is driving around a field continuously, it will, after ten times, know more about which places it should study more closely.*

The subject with background from development of UID technology points to the use of, and development of indicators for monitoring the operation. Today, alot of data is accessible, but the useful information has to be extracted from the masses of data. Developing indicators can help with the processing of the data, and be applied to give an indicator of the resilience of the system. Indicators could be helpful in the process of identifying sources of resilience.

The other subjects focuses on the future possibilities, with examples such as the use of machine learning for self-repairing mechanisms, automation of operations, and development of algorithms to prioritize between installations. Applying machine learning would imply an increase in automation level of the system. This again would reduce the role of the human operator.

Dependencies and interactions

The company's understanding of interconnections in the operation, and understanding how variations can propagate through the system were also examined. The main results are presented in table 4.12.

Table 4.12: Identifying sources of resilience: Dependencies and interactions

Dependencies and interactions	
Interview subject with background from:	**Findings:**
Development of UID technology	*We are working on getting standardized docking stations into the APIs. We think they should be able to stand and be somehow available so that we can use each other's docking stations in the future. Then it is critical that no one comes and uploads our mission data. So the connection needs to recognizing which drone is coming, so that it doesn't give access to anything so that suddenly another operator can sit and steer our drone.*
Marine operation and control center	*One challenge is if you set up such a drone with several tasks. Then you build organizations that rely on the data. And it is clear that when one drone gives data to many units, then it is clear that when one fails, then many people struggle.*
Development of UID	*No, i don't think there is much potential for these kind of events with UIDs, as events have limited consequences. There is low mass, and slow tempo in the water, so i think the potential is very small.*
UID implementation	*This is something that we work with our suppliers who develop drones and drone technology on. We don't have a good answer today. But we cannot leave a drone to interfere with systems through hydrocarbons, overpressure, and the risk of damage without having a good backup and protection to prevent this from happening.*
Subsea and ROV	*Yes, if it destroys a pipe, operates the wrong valve, does something wrong with an electrical connection, gets stuck in a cable, etc . There is a lot that can go wrong. This is the case with ordinary operations as well.*

Many of the subjects point to a potential for cascade effects in the operation. The subject from UID implementation point out that this something they are working on in collaboration with suppliers, and needs further work in the future. The drone is to perform tasks around systems containing hydrocarbons, with high pressures and other risks, it is important to avoid unwanted interference between the drone and the systems. This is also pointed out by the subsea and ROV subjects, who considers it a possibility that the drone could come in contact with, and cause damage to pipes, electrical connections, get stuck in cables or similar events. Such events could have propagating effects and potential impact on production and environment. Its important to develop an understanding of how systems are interconnected, and how variabilities and events can propagate through the system. The FRAM model in section 4.1.3 considers functional resonance in the system. This shows how small variabilities can cause events as a result of unintended interactions. Trying to understand the interactions that might occur is therefor important to reduce unwanted interactions. The subject from development of UID however, does not see a big potential for events with propagating consequences, as the drones have low mass and operate with a high degree of inertia.

The interview subject with background form development of UID technology talked about the ongoing work of standardized docking stations that can be used by different companies and drones. Here they point out that this interaction with other companies might create a need of drone recognition when connecting to the docking station, to assure that access to mission data is only given to the operator that is supposed to have it. The subject with background from marine operation and control also pointed out that using a drone for multiple tasks, might create a dependency, were different organizational units all depend on data from one drone. If many organizational units, or many companies, all depend on the same drone, failure of the system will have affects for many actors.

Learning

An essential part of resilience management is learning from what makes the operation successful. The questions directed towards this ability are intended to identify the capabilities/characteristics of strategies, practices and procedures that help the operation to succeed, to be able to learn from these. The key findings from this topic is presented in table 4.13.

Table 4.13: Identification of sources of resilience: Learning

Learning	
Interview subject with background from:	**Findings:**
Development of UID technology	*It's essential to learn from things that are going well.* *We have very good systems for the follow-up of events.*
Marine operation and control center	*In practice, this will be a development of our governing documentation. And they are under updating, based on input and improvements.* *You can digitize a plan reasonably well, continuously monitor it, and immediately update where you are according to the plan.*
Development of UID	*We have something called Synergy, but it is mostly focused on unwanted events that we register in a computer system. When we are going to perform operations, we conduct a search and see if we find any experience reports from similar events, or drones, if there were any events there, then we learn from them.* *And then there is the technical requirements, the requirements based on 30-40 years of experience in the company. So based on experience, we make specific requirements that we ask the suppliers to follow.*
Subsea and ROV	*We may not be the best at that. Sometimes we have experience meetings and summarize operations, but mainly if things have not gone according to plan.* *We usually register lessons learned or things that can be done equally later. Also, we update procedures and programs based on the experience.*

The subjects mentioned systems for follow-up of events, development of governing documentation, follow up on digital plans, technical requirements and experience meetings. But, as mentioned by the subjects from subsea and ROV, the findings from the interviews conducted indicate that the company has developed good systems for learning from what goes wrong, and that the potential for learning from what goes right might not be fully utilized. The experience meetings are a good method for sharing experiences after completing an operation. However, if the focus is not on actions that lead to success, this experience will not be exchanged. In the FRAM model in section 4.1.3, after work review is set as a function that could potentially reduce the variabilities if performed correctly. Learning is one of the four cornerstones of resilience, and is essential for the system to build its ability to respond. Getting in place systems to facilitate this ability is therefor a good way to improve resilience throughout the operation.

Identification of Sources for Resilience: Summarized

Through the questions related to the *Identification of Sources of resilience* capability card, it was found that the operation has a range of strategies, tools and methods that could contribute to successful operation and improved resilience. Expertise, knowledge and experiences from years in the business, and from similar operations exist both in the oil company, and at the suppliers. Through close collaboration, and with good coordination, these can be applied in the operation. Strategies related to learning algorithms and further automation was also identified as possible sources of resilience. However, these are considered developments for the future, and are not part of the operation to begin with. With a large amounts of sensors, vast amounts of data is collected when performing operations. If the essential data can be extracted from this data, there is a big potential to learn.

The findings also show that there are interdependencies and possibilities for propagation effects in the system. These should be mapped out and understood to avoid unwanted interactions as a result of variabilities. The results also show that there might be more uncertainties in the startup of the operation, with more trial and error. To reduce the risk of this, the drones can be applied to less critical operations in the startup phase. The company has many systems developed for learning from what goes wrong, but does not have the same experiences of learning from what goes right. There is therefor a large potential for improvement in order to properly utilize the experience and lessons that can be gained from the sources of resilience that have been identified here.

It is important to keep in mind that the operation has not been initiated yet, and that for these sources of resilience to have an effect, they have to be applied in practice. Most of the sources of resilience identified, also seem to require further development. In regards to the machine learning and automation solutions, this seems to be a source of resilience that is applicable after a longer time frame. Systems for learning from success, although not established in the company today, should be applied for the operation. The subjects also identify a challenge related to their ability to anticipate, as the operation is new and there are no direct experiences with this new technology. This would constitute a brittleness of the operation in the startup phase. The brittleness in the operation is further investigated in the following section.

II. Noticing Brittleness

As mentioned in section 2.8.4, this capability is expected to allow the organization to address its sources of brittleness, and the underlying factors. By identifying the sources of brittleness, the organization can avoid events that results in possible harm or damage by implementing measurements to improve the resilience. The organizations capability to notice these sources and underlying factors in the remote operation, was examined by the following abilities;

1. **Lack of Resources:** Does the operation have the human, technical or material resources available? (DARWIN, 2018b).

2. **Lack of Information:** Is the necessary information needed to conduct the operation available? (DARWIN, 2018b).

3. **Goal Conflicts:** Are there possibility for internal or external conflicts for the operation? (DARWIN, 2018b).

4. **Constraints and Bottlenecks:** Are there possible situations where the system is constrained, or bottleneck occur as a result of workload? (DARWIN, 2018b).

5. **Difficulties to Adjust:** Are there barriers to adjust or adapt when needed? (DARWIN, 2018b).

Lack of Resources

Here identified possibilities for situations where the expected resources are unavailable in the operation were examined. The findings are presented in table 4.14.

Table 4.14: Noticing brittleness: Lack of resources

Lack of resources	
Interview subject with background from:	**Findings:**
Development of UID technology	*Yes, of course, it can happen. After all, we do everything we can to plan, prepare to prevent it. But then it can happen..*
Marine operation and control center	*In the expertise in the system and structure, from design to production, and from production into operation, we see that we often fail in IT systems, technology, and things like that.* *Then they are currently making the offshore organizations extremely lean. They want no more people then what is necessary to operate the platform and operations like this might go through the platform.... Then it is a challenge that it is very lean. ..if things fail, you most likely need a boat to go out to retrieve or maintain those things there. And what types of boats do you need, and what kind of availability do you have for these types of boats to respond quickly enough, is also a thing. So vessels can be a limitation.*
Development of UID operation	*There are no operations that go entirely as planned. So this has to be taken into consideration. It will probably happen several times.* *If you lack resources you have to delay or restart the operation. You should obtain the resources before you start or during operation. It is not so good to start during operation, you should have it done before you start ....*
UID implementation	*...lack of resources is quite often a problem.* *...if we do not have enough resources to do a job, in regards to safety and risk management, then I would never approve initiation of the operation. So it becomes a show stopper.*

As presented in table 4.14, the subjects agree that lack of resources could potentially be an issue. The subject with background from marine operation and control center mentioned that the company often fail in the availability of expertise for IT systems and technology, systems highly relevant for the remote operation. He also points out that the development of lean offshore organizations, a philosophy focused on optimization of time, resources, assets and productivity in business processes by elimination of elements that cost money or time without adding value. Lean thinking is mainly focused on financial factors by removing slack in the system, and can therefor be viewed as a contrary to resilience (Shah and Ward, 2003). A focus on lean can therefor challenge the systems ability to respond to event, restore from disturbance, the systems ability to handle challenges and the ability to stretch its performance due to the reduced availability of human and technological resources.

The subjects from development of UID implementation says that the initiation of a job would never get approved if the necessary resources are not available. This is simpler for pre-planned inspections such as the one suggested for the subjects in the interview. But if the company begin with a check and report operation, cases where the resources are not available are more likely. The subject with background from developments of UID operation points out that resources should be obtained before, or if necessary during the operation. As the subject further pointed out the initiate priority should be to obtain the objects before, but situations leading to lack of resources can occur under the operation, and therefor the needed resources can be obtained under the operation as a attempt to save the operation instead of stopping it.

The findings indicate that lack of resources needed for the operation might be a challenge, especially regarding the expertise needed for IT systems and technology. Also, the focus on lean organizations might affect the access to resources.

Lack of Information

This section focus on the possibility of lacking information during the remote operation, and the possibility to use experience from similar operations to make up for some of the insufficient information. The key findings in the conducted interviews are presented in table 4.15.

Table 4.15: Noticing brittleness: Lack of information

Lack of information	
Interview subject with background from:	**Findings:**
Environment surveillance	*We have used drones for a long time.....But to use drones for intervention, and maintenance near platform and rig and such, is new. But yes, you have to use the gained experience.*
Marine operation and control center	*Yes, but it is not that high-tech. We have a lot of experience with AIS-signals. We get info from all our facilities, and then people sit in a control room and interpret it and act based on the status of those signals...* *..From the assessment of some operators to the team's, the whole setup of a control room, and the support of those who receive the signals, that they work well, can make a huge difference.*
Development of UID operation	*We use a lot of the experience we have when planning new operations and planning new technology. It is alpha-omega to understand what you are doing. But, you can think a little out of the box to. Some of the suppliers have no operational experience, and come up with slightly different solutions than the traditional company's.*
UID implementation	*Certainly, but basically, we who are on the operator side do not do the detailed planning and management of the ROV operation itself. Here, the people in operation prepare an overall work program.*
Subsea and ROV	*I imagine that the company's that develop the drones are such company's that operate in the conventional ROV industry, and they have experience from that. After all, the oil company's do not have direct hands-on experience with ROV operations.*

The interview subjects with background from environment surveillance, marine operation and control center, development of UID, and UID implementation seems to agree that existing experience from similar operations will be applied to cover some of the lacking information in the UID operation. Examples they mentioned were interpretation of automatic identification system signals (AIS-signals), satellite data used for monitoring of vessels, and prevention and managing of accidents (The Norwegian Coastal Administration, 2011). The experience and knowledge gained by the set-up of existing control rooms in the company, such as Valmon control room, that can contribute when developing control room for the remote operation of UIDs. And organizational and management factors, such as planning of new operation and technology, and support of operators receiving signals to facilitate a well-functioning work environment.

While the subjects with background from subsea and ROV points to the potential experience laying at the suppliers, the subject with background from development of UID operation, points out that not all of the suppliers have operational experience with drones and remote operation.

The results indicate that some lack of experience and knowledge regarding the UID operation, has to be expected for operation under development. However, experience within similar operations existing in the company can be useful in this process. There seems to be some inconsistency in regards to the expectations the subjects towards the suppliers experience level, and their ability to contribute to reducing this lack of information.

Goal Conflicts

This section focuses on the possible conflicting goals in the UID operation, both internally in the organization, and externally between the organization and the contractors involved. It also considers how priorities are made in such situations.

Table 4.16: Noticing Brittleness: Goal Conflicts

Goal Conflicts	
Interview subject with background from:	**Findings:**
Development of UID technology	*If something happens in two fields at the same time, then we must have thought through some guidelines or decision criteria regarding who gets access to drones first.*
Environment surveillance	*Yes, that can happen....Then there must exist an easy to handle plan for how to prioritize.*
Marine operation and control center	*..if you have multiple operators who need the drone to provide input for various operations, you may have to choose between them.* *Having a process and a prioritization regime purely operational is essential. And those who are at the sharp end and may have to choose and prioritize, if not fully automated, there can quickly become a conflict.* *And regarding uptime. It can be something as simple as here in the control center, like the servers that supply power, etc. They have, in the contract, an uptime of 99.9%. The document that regulates the uptime on the platform where they have the sensors that give us data, they have a required uptime of 99.8%. So the question then is, what is right? To get to 99.8% here on land you have to build more redundancy and extra barriers. And that costs money. But in our contract it says they will deliver at 99.5%, and thus they will not spend more money to reach a higher level.*
Development of UID operation	*No, I don't think so. Not so much strain that there is conflict in the use of drone.*
UID implementation	*...if there are two jobs, you must prioritize one. Then the licenses must be considered with their cards. Consider the safety, the environment, and the financial aspects, and prioritize based on this.*
Subsea and ROV	*It may be that you do not have the right type of contract. You can get into a situation where the operator has given a fixed price and wants to be finished quickly. Thus, they do not think much about the quality.*

While the interview subject with background from the development of UID operation considered that goal conflicts would not be an issue in operation, due to lack of strain on the system, the other subjects seemed to agree that this could be an issue. Two possible issues were pointed out; issues caused by the contract model in the form of availability and financial interest, and lack of technological resources to handle all ongoing events, leading to a need to prioritize between tasks.

To handle the issue regarding the contract model, the subject with background from marine operation and control center mentioned the balance of availability given in the contract, and the subject from subsea and ROV, the contract type to avoid conflicting goals between the contractor and the company. Regarding the priority of multiple tasks, the subjects with background from the UID development, and marine operation and control center, mentioned the use of guidelines or a prioritization regime for access to the drone.

Constraints and Bottlenecks

Possible situations where the system is constrained or bottlenecks occur as a result of workload based on the interview subjects' experience with similar operations in the organization, are presented in table 4.17.

Table 4.17: Noticing Brittleness: Constraints and Bottlenecks

Constrains and Bottlenecks	
Interview subject with background from:	**Findings:**
Development of UID technology	*You observe something under an operation. How long should the drone detect more vs. move on? It's something you have to build algorithms for, and something we have to consider.* *If something happens on two fields simultaneously, we must have thought of decision criteria in advance, that can be utilized at the lowest possible level.*
Environment surveillance	*The sea depth and battery life, losing contact, and losing communication are things that can happen...*
Marine operation and control center	*If you have multiple actors within the same product or drone, what do they want to achieve with the drone, and who is at the top of the hierarchy? Who decides if a conflict arises?* *There may be a conflict between those who deliver the system and those who..yes .. back to goal conflict then. It is not so urgent for them, because they are still within the contract limit. But those who use the data are struggling.*
Development of UID operation	*When you don't have a human on a vessel that can make changes to a tool or something, it's harder to have something done about it. Compared to today's operations, there is a higher likelihood of not getting operations conducted when something unforeseen occurs.*
Subsea and ROV	*During operation, you discover something that should be handled, but the drone lacks the capacity to do anything. Then it just has to report this.*

Both the subjects with background from the development of UID and from subsea and ROV mentioned the drone's capacity as a potential challenge on the system's limits. Both pointed to observations made under operations, and how these should be handled. As pointed out by the first subject, this is an issue that must be considered in the human-operated operation, but also a challenge when building algorithms for the drone operation. Another challenge mentioned by the subjects from subsea and ROV were possibilities for lack of capacity to handle issues discovered under the drone inspections, and events where the drone is needed in multiple locations.

Another challenge pointed out by the subjects with background from environment surveillance and development of UID operation is the occurrence of situations that hinder the ability to perform the operations. This both due to technical issues and the lack of access to the personnel available to solve the issues.

Also, the subject with background from marine operation and control center mentioned situations were operations serve as a constraint for other organizations, in the form of goal conflicts due to contract limits. The results indicate a risk of constraints and bottlenecks due to limitation in the contract such as the time of availability of expertise and payment methods, were a fixed salary instead of an hourly rate might lead to suppliers more focused on finishing the task, rather than performing a thorough operation.

Difficulties to Adjust

In this section the involved barriers ability to adjust and adapt when needed is studied. This involve the capacity to relocate resources, and deviations between WAI and WAD. The key finding are presented in table 4.18 and 4.19.

Table 4.18: Noticing brittleness:The ability to adjust I

Difficulties to adjust I: Relocation of resources	
Interview subject with background from:	**Findings:**
Development of UID technology	*It is a maturation process. How to start and what skills you need in different locations. At the supplier, at the company. Do we need to build some expertise ourselves?*
Environment surveillance	*Yes, if you mean people by resources, then I think so, if not huge, I think. I don't think it will be such a shock, but a gradual phase-in of such a drone way of working.*
Marine operation and control center	*It is not a problem of competence but more of an interpersonal problem. ....organizational challenges and interpersonal challenges more than practical is my assertion.*
Development of UID operation	*In terms of people, if we start with that, then we will operate in a different way, we become more familiar with our facilities, and we have drones that can film and do jobs in a much more cost-effective way, meaning we can use these drones a lot more. We get something positive from the fact that we become more familiar with our installations and get more control over technical integrity. Then again, when it comes to the installation itself and the technical, the future subsea installation may be designed a little differently because we have these drones present. There may be simpler installations that need smaller, simpler valves and less technology actually on the installation. And designing this differently also, because it must surely be done, place things a little differently in terms of the accessibility of the craft.*
UID implementation	*The capacity to relocate resources is a constant discussion. But yes, those who manage the resources relocate people all the time.*
Subsea and ROV	*This happens relatively often. You had a plan for something to do, and then you ran with troubleshooting or something, and it turns out that it does not work, and you have to test something else. And then they use management of change were all changes must be recorded, and things have to be done differently than initially intended.*

Issues related to the need of resources, and the ability to relocate them when needed were pointed out as a maturation process by the interview subject with background from development of UID technology. This was supported by the subjects with background from environmental surveillance and development of UID operation. While the subjects with background from UID implementation, and subsea and ROV pointed out that relocation happens often in the company. The subject with background from UID development mentioned that this is a constant discussion in the company, that also support the quotation regarding the focus on lean in the organization, found in the section 4.2.1. The results indicate that some issues under the familiarization process is to be expected, but the company seems to have some experience with relocation of resources, that can be useful in this process. The findings can indicate that the focus on lean in the organization might be a barrier against the slack in recourse's, necessary to achieve this capability.

Also, the interview subject with background from marine operation and control center stated that the company had interpersonal issues when it came to the peoples mobility and the mentally preparedness to help others, rather than lack of competence. This indicate a need to focus on the organizational challenges, rather than lack of competence off personnel, when establishing resources during the startup phase of the UID operation.

Table 4.19: Noticing brittleness:The ability to adjust II

Difficulties to adjust II: WAI vs.WAD	
Interview subject with background from:	**Findings:**
Development of UID technology	*We have a high focus on compliance and must take that with us into the situation. Then you have, this compliance and leadership model, which has come as an essential tool for us for just that. For you as a manager to be clear of what expectations you have for the employees and enable them to do so. Because if they do not follow the procedure, then there can be some good reasons for it. That they don't really understand the procedure, they think they have a much better way of doing it. And then the procedure may need to be updated. Is it outdated? And from a management perspective, you have to understand why, and then make people follow the procedure. And listen to them, which is very important when it comes to improving the procedure.*
Environment surveillance	*I do not have enough operational experience to think that much about it. My experience is that you follow the governing documentation. And do good safety analyzes, risk analyzes, comprehensive risk analyzes when planning for testing.*
Marine operation and control center	*Yes, it is a hundred percent certain that there will be a difference in how you do it. However, if you are good at governing documentation and procedures, referring to what we talked about in our operating room. We can see it on the people when things are organized, that there are good and up to date procedures. It is also important that they are continually changing and evolving. If you have a good structure on it, if you have system support, like the one here, then they are, then it is quite possible to be very close to what you write and what you actually do.*
Development of UID operation	*We usually have very detailed procedures. And we shall follow them. However, then it happens from time to time that you have to change. Then you stop the operations, and you make a change in the group, it gets approved, and you continue. It will probably be neither more nor, I think it will be at the same level as we have today, I do not think it will be more or less.*

As presented in table 4.19, the interview subjects with background from environmental surveillance point to an experience of compliance of the governing procedures. They suggest a reduction of deviations in the start up and test phase by a applying an safety I approach, as described in section 2.7.1.

The interview subject with background from development of UID technology also talks about a high focus on compliance in the company, and how they can facilitate compliance through use of a compliance and leadership model. A management tool they apply for continuous improvement of the procedures by involvement of the people using them, focusing on why they deviate from the procedures. It looks at whether they do not understand the procedures, or if they have alternative ways of performing the tasks that deviate from the procedure. Based on this, the procedures can be updated to be more understandable, or to include new and better approaches. This represent a safety II way of thinking as presented in 2.7.1.

The subjects from marine operation and control center, and development of UID operation both expressed that a difference between work as imagined (WAI) and work as done (WAD) will exist, a claim that seem to be supported by the theory presented in section 2.7.2. Even when the procedures are followed exactly, there might still be some degree of variability.

Noticing Brittleness: Summarized

Through the questions related to the *Noticing Brittleness* capability card, different possible sources of brittleness was identified. Lack of resources, both human, technological and organizational could occur. One example based on experience of one subject is the expertise needed for IT systems and technology. It was also expressed that the focus of lean might contribute to this issue. Lack of information was also identified as a brittleness. Some information based on similar operations could be applied, but considering that the operation is new and little experience exists some information is unattainable. Information lies with both the oil company and the suppliers, but there is some inconsistency with the subjects expectations to the experience and contribution of information from the suppliers.

Another possible source of brittleness is goal conflicts. This in regards to the need of drone in multiple locations at the same time. In the initial face of the operation, there will be little strain on the drone. In future development, if the scope of operation increase, the probability of these kinds of conflicts can escalate. The drones capacity was identified as å possible constraint. Events like battery life and losing communication with the drone is highlighted. Also the availability of human resources to perform necessary maintenance. The systems capabilities might also be challenged if the drone is applied to multiple fields, with multiple tasks.

As can be seen in figure 2.14 in section 2.8, noticing brittleness is a complimentary capability to identification of sources for resilience. The two identifies strengths and weaknesses in the operation. Some of the sources of resilience identified could be able to reduce the brittleness if improved. Thus the brittleness could be reduced. If however, the sources identified are not implemented, brittleness might increase. As mentioned, the UID operations have yet to be implemented and tested. Thus, the brittleness identified here could be dealt with before the system is implemented, and there could also exist brittleness that has not been identified here due to lack of experiences and information regarding the operation. There is also a possible that new brittleness surfaces in the future when the operation develops, and more strain is put on the system as compared to the startup phase.

4.2.2 Supporting Coordination and Synchronization of Distributed Operations

Further, the company's ability to support coordination and synchronization of distributed operations during the UID operation was examined. This ability was focused on the interview subjects' experience with the oil company's ability to share information on roles and responsibilities both between its departments, and with contractors. To do so the following resilient management capability was addressed;

I. Sharing information on roles and responsibilities

As previously mentioned in section 2.8.2, this capability is directed towards the understanding of roles and responsibility for the actors involved in the operation. To examine this capability the following abilities were studied;

1. **Involvement of organizations:** To what degree, and how the organizations are involved in the managing and operation? (DARWIN, 2018b).
2. **Coordination mechanism:** Is there a periodical coordination between the actors, and is the responsibility for this coordination clearly appointed to one of the actors? (DARWIN, 2018b).
3. **Impact on organization:** How changes in one of the organizations can affect other organizations involved, and are these changes communicated to the affected actors? (DARWIN, 2018b).
4. **Internal dissemination of changes:** Are information and training given on relevant changes and roles. And will a quick reference guide be provided for identification on roles and actors relevant in the operation? (DARWIN, 2018b)
5. **HMT:** To what degree will the operation be preprogrammed, and how will the roles between the drone and the operator be distributed? (DARWIN, 2018b).

Involvement of organizations

In this section the company's ability to involve the relevant organizations to handle and plan for joint and parallel operations are studied. For this examination, a situation where the oil company has a check and report operation, and the supplier has an inspection operation was suggested to the subjects. The event where the need for a check and report operation occurs while an inspection is being carried out was considered. The key findings are presented in table 4.20.

Table 4.20: Sharing information on roles and responsibilities: Involvement of organizations

Involvement of organization	
Interview subject with background from:	**Findings:**
Development of UID technology	*Yes, you have to think about what you need, what is important that is prioritized? And how to set up, in a way, material models, where it is possible to get to then. Because if we have a higher priority on certain types of assignments from the supplier, that creates commercial consequences. For them to be prepared to respond, it is all about emergency preparedness agreements. After all, it's a cost-benefit assessment, having an agreement that gives you a higher priority.*
Marine operation and control center	*I think that is quite possible to solve. For the benefit of a work process, it is that it does not matter whether if it is the company or a supplier. It defines what needs to be done, what task is to be performed. And if there is a need for clarifications, then we have to agree on who makes those clarifications, also you may need to have a defined priority list if those who talk together do not agree. And then you have to be clear about who is in charge.* *I think it is incredibly important to identify, where you raise issues and that they are prepared to address them.*
Development of UID operation	*No, because it's not that often we have operations in our fields, so it probably won't happen. We may need to change ... it may be, for example, that we perform an operation and get a stop due to an unwanted event or we have to stop and think.*
UID implementation	*If we are planning a less important operation, but there is an operation that needs to be done, as you say a check and report for equipment in a component, it is usually a priority case so that a less important operation is postponed so that drones or vessels can skip some more important missions.*
Subsea and ROV	*This happens all the time. If a higher priority job is needed when another is ongoing, then you have to stop the other. That's the way it is today.*

The interview subjects with background from development of UID operation, UID implementation and subsea and ROV points to the existing experience within prioritization of task. This could imply that if the need for the check and report operation is critical, the scheduled inspection has to be put on hold so that the check and report operation can be conducted without the risk of unwanted interaction between the two operations. It is indicated that the company has usefully experience within prioritizing of tasks from existing operations, that can be applied in the remote operation.

Further, the interview subjects with background from development of UID technology and marine operation and control center focus on how these prioritizes of assignments should be defined. The subjects suggest use of priority lists that have to be divulged and clarified for all actors involved. The subject with background from UID technology also focused on agreements with the suppliers, and the cost-benefits consideration connected to this. The subject from marine operation and control center also pointed to the importance of identification of where these kind of issues should be raised, so that it is possible to prepare to deal with these before they surface.

The subjects seem to express the common opinion that setting priorities and making decisions when situations of parallel operation occurs, is the responsibility of the oil company. Further they express that the set of rules that is set for the operation has to be communicated so that all involved parties have a common understanding of these.

Unlike the other subjects, the subject from UID operation points out that operations such as these UID operations are not that common, and that the situation with parallel operation is not probable. However, being prepared for the possibility of such an event would reduce the probability of unwanted events as a result of poor coordination of the operation. In the startup phase, it is unlikely that many different operations will be implemented at the same time. This is therefor an issue for future consideration when the use of drones expands its scope. Possible issues should be addressed before such an expand is made, anticipating possible consequences this could generate.

Coordination mechanism

In this section the oil company's ability to coordinate activities, procedures and periodic coordination's of the activities with the involved organizations is examined. The key findings are presented in table 4.21.

Table 4.21: Sharing information on roles and responsibilities: Coordination mechanism

Coordination mechanism	
Interview subject with background from:	**Findings:**
Development of UID technology	*Often, it is the suppliers who are responsible for the procedures for the operations they conduct. Then we have requirements that we would like to set, where we can have procedures or governing documentation with us that give requirements for that procedure.*
UID implementation	*I think we must still carry the overall responsibility.*

Like the inconsistency identified in the examination of the company's ability to handle lack of information, the findings of the coordination mechanisms also can indicate an inconsistency in the expectancy towards who will be in charge of the procedures for the operation. While the interview subject with background from development of UID technology indicate that the suppliers should be responsible for the operations procedures of the operations they conduct, based on requirements from the company, the subject from UID implementation considers that the oil company has to sit with the overall responsibility.

In the FRAM model in section 4.1.3, the task of developing procedures is considered as a cooperation between the the oil company and the contractor. The model also considers that mission plans are the responsibility of the oil company, as the operations are carried out on their installation. This model fits with the opinions of the subject from development of UID technology. From both subjects opinions it can be concluded that the work related to procedures for the activities has to be performed with some degree of collaboration between the actors. It is also important that there is a common understanding of procedures and plans, to reduce variability as a consequence of errors in procedure or communication of the procedure.

Impact on organization

Here the impact of changes in one organizations roles and responsibilities, has on the other is examined. The key findings are presented in table 4.22.

Table 4.22: Sharing information in roles and responsibility: Impact on organization

Impact on organization	
Interview subject with background from:	**Findings:**
UID implementation	*It can have an effect in both directions. Both positive and negative. Negative if, for example, a resource with long experience disappears, then new people come with overlapping and training that is not so effective. In such an introductory phase to say, it can be a few weeks or months. But at the same time if people are good at handover, with clarification with new personnel, then this can be fine.*
Subsea and ROV	*If we change the organization, we will still be in line with the command line. Changes to this will be handled by us. If that changes in the operator's organization, then I expect them to let us know, so that you know who to contact for communication to continue "seamlessly."*

The interview subjects with background from subsea and ROV pointed out that internal changes within the company would be handled internally, but that if changes on roles and responsibilities at the contractor were made, they expected the contractor to inform them. The subject from UID implementation expresses that changes could have effects for both organizations, positive or negative. Changes in roles and responsibility could lead to loss of experienced personnel, and new personnel would require a period to be introduced to the new responsibilities. Such changes should therefor be planned. It could be possible for a new person to come onboard before the previous person disappears, so that experiences could be exchanged.

There needs to be communication between the actors on who holds what roles, and what their responsibilities are. This way everyone involved will be aware of who to contact in different events, and better relations can be formed between the companies. This would also make changes more seamless, and variabilities related to such changes would be minimal. This is further addressed in the following section.

Internal dissemination of changes

In this section the company's ability to provide information and training to involved staff, when roles and responsibilities of one of the actors change is examined. Also, the ability to communicate between the organizations in joint and parallel operations were studied. The key findings are presented in table 4.23.

Table 4.23: Sharing information on roles and responsibilities: Internal dissemination of changes

Internal dissemination of changes	
Interview subject with background from:	**Findings:**
UID implementation	*It is essential to have a proper flow of information, and also that you have to prepare a plan. For example, if you list what new personnel to be taught, should learn. Training plan with different points on the practical, on the theoretical, etc. But it is often performed as on-job training....* *..an assessment or a small HAZID must be prepared in advance. And the risk is identified and recorded. And a matrix is being prepared. And there are two representatives on two vessels that have to talk together, first and foremost, if they are comfortable because they are close to each other. And that they coordinate various activities. ...in a critical phase of operation, then one must chase away the other for a while.*

The interview subject with background from UID implementation expresses that it is essential to have a good flow of information, both internally and externally. A plan should be prepared to deal with changes in either of the organizations. In addition, the subject also suggest having a training plan for new personnel. The training should give them the basic information, both on practical and theoretical knowledge required. In addition, a lot of experience is gathered in an on-job training setting. As mentioned in the section above, changes in roles and responsibilities could cause a loss of experience if the change is not done in the right way. However, in some situations roles and responsibilities might need to change over a short period of time do to unexpected events, and the actors involved need to coordinate and communicate in a way that assures that such abrupt changes can happen smoothly. Having close communication between the actors also ensures that the parties are comfortable with each other, which facilitates better collaboration if changes happen.

Human Machine Teaming (HMT)

In this section the expected degree of automation of the UID, and the distribution of roles and responsibility between the operator and the UID is examined. The main findings are presented in table 4.24.

Table 4.24: Sharing information on roles and responsibilities: HMT

HMT	
Interview subject with background from:	**Findings:**
Development of UID operation	*Over time I think it will be preprogrammed based on machine learning and experience. But at the start, I think it's necessary to start controlling the drone from an onshore control room. Then it will gradually be an increasing degree of autonomous functions, controlling more and more of the operation.* *But given the values at stake, I think there will always be some degree of human decision making and control.*
UID implementation	*First, these drones will be controlled from land, but preprogramming will be the next step. But I'm a little afraid it's too early to give a reasonably safe answer.*
Subsea and ROV	*Use of machine learning to memorize the operation/ increase effectiveness.* *When it comes to decisions there need to be clear limits with safety margins for what it can, and can't do.*

The answers presented in table 4.24 indicate that all the subjects expect some degree of automation in the operation. This is also reflected in the *identifying sources of resilience* section, where machine learning and automation are suggested as future strategies for the drones. However, the interview subject with background from UID implementation believed that it was to early in the development to give an answer in regards to what extent the operation will be pre-programmed.

In the starting phase, the drone would have a lower autonomy level, and be human operated as described in table 2.1 in section 2.1. This implies that the operator has full control of the drone. The subjects with background from development of UID operation and UID implementation both were under the impression that a degree of automation will be implemented through a gradual process, firstly being controlled from land. And the subject with background from development of UID expected there to always be some degree of human decision making or control, meaning the drone will not be fully autonomous, as defined in table 2.1.

How the resilience is affected by an increasing level of autonomy is difficult to predict. While basing decisions on learning algorithms and sensor data could eliminate some human errors and variabilities, there is a possibility that new types of variabilities surface. As long as there is a human in the loop, considerations have to be made to the interface between the human operator and the drone, and how they interact with each other. As explained in section 2.4, the design of the interactions between human and machine requires careful consideration to function sufficiently. This to facilitate a common understanding between the system and the operator, and allow for the system to adapt to unexpected situations where human interaction might be needed. If the human machine interaction is poor, variabilities could surface due to errors by operator, errors in the system or misunderstandings between the system and the operator.

Sharing information on roles and responsibilities: Summarized

Through this capability card different aspects related to the coordination and collaboration between the involved actors has been further considered. The interviews reveal that the oil company has to set rules and priorities for operations to be performed on their installations, to avoid unwanted interactions as a result of parallel operations. This information has to be communicated to the contractor to ensure a common understanding. Further, the development of procedures and coordination of these has to be performed in collaboration between the oil company and the contractor. The oil company sets the requirements and rules as the operations are located at their installation, but involving the contractor ensures common understanding, and reduce variabilities as a result of errors in procedure or poor communication of the procedure.

The roles and responsibilities within the organizations might be subject to change. When such changes happen, it is important that there is a communication between the actors to convey these changes, so that variabilities as a result of these changes are reduced to a minimal. Having a plan that deals with such changes, as well as a good relationship between the actors ensures that such changes are smooth. Close cooperation also builds trust between the organizations that facilitates for a sudden change of roles and responsibilities in the face of unexpected events.

The division of responsibilities between the drone and the operator also has to be considered, if in the future the system achieves a higher level of automation. The interface between the operator and the system then has to be carefully designed to avoid errors as a result of misunderstandings between the operator and the system.

Chapter 5

Discussion

In this chapter, the results are discussed using the relevant theories introduced in chapter 2. The main topics discussed are how the DRGM can be adapted and applied to improve the resilient management for remote operations in the petroleum industry. A topic that was examined by interviews using the capability cards given in the DRGM.

5.1 Adaption of the DRGM

This section is focused on how the DRGM were adapted to the case operation. The adaption of the guidelines was performed through the process showed in figure 5.1.

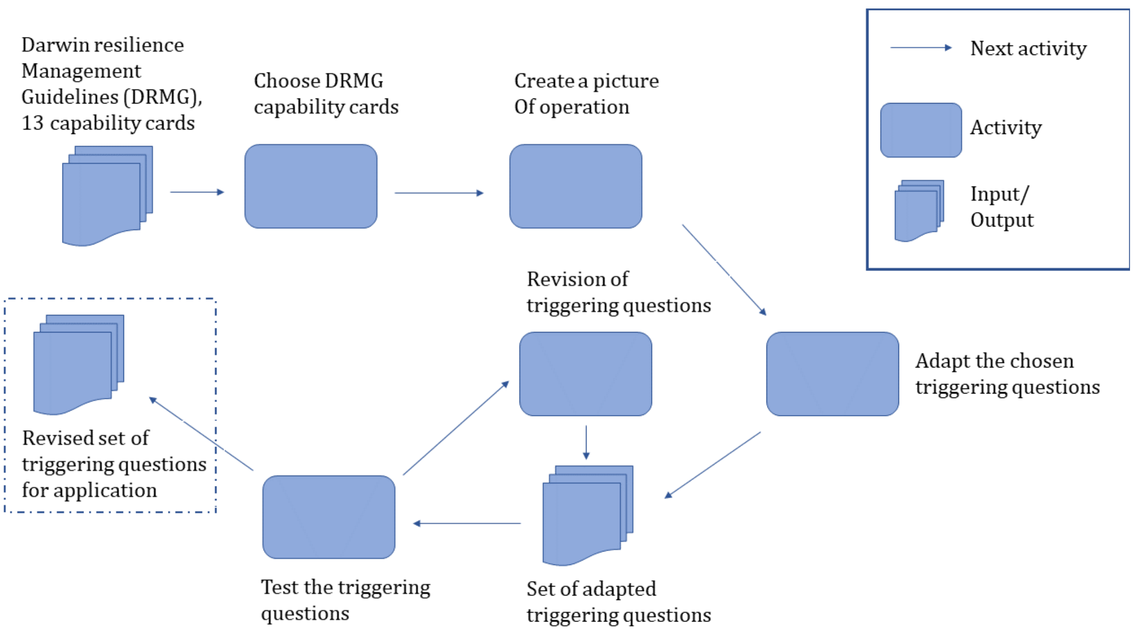

Figure 5.1: Process of adapting DRMG to case

The main challenge of the adaptation is that the DRMG is originally developed for resilient management of crisis, while in the thesis the focus has been on the everyday operation. A crisis is defined by ISO (2018) as a *Situation with high level of uncertainty that disrupts the core activities and/or credibility of an organization and requires urgent action.* As the definition points out, crises are events that threaten the operations expected function and outcome. and require an extraordinary and sudden response through reorganizing and gathering resources. The ability to respond depends on the ability to communicate effectively between the actors involved in the operation, and knowing how to respond to these events. The everyday operation represents the successful operations that are performed often, and are not subject to the same level of uncertainty. The differences between these have to be considered through the adaption, as the focus areas for the resilience management of the two would differ. The two first steps in the adaption therefor seeks to identify the commonalities between the two, and what capability cards and associated triggering questions would best be fit for the case operation. The three capability cards chosen where selected based on their maturity, but also because the themes of the cards are fitting for the case.

To select the best triggering questions, the second activity in figure 5.1 is to create an understanding of the operation. This was done through a set of analyses that covers human, technological and organizational aspects, as well as the relations to other actors. Due to the operation in the case being in the development and test phase, not much information is available, and such analyses can help reveal aspects of the operation that affect the resilience. For an operation that is well established, the operation could also be mapped out through documentation and conversations with those who participate in the operation. This in combination with the analytical methods could give a clearer picture than what was created in this thesis. The results of the analyses performed, as shown in sectionsec:, reveals that everyday operations could encounter similar challenges as in crisis. Some of the reason for this is the increasing uncertainty, complexity, and tight couplings in systems today.

Crisis management involves many different actors, that all needs to be coordinated. In a crisis, this can be difficult as a result of the uncertain nature of the event. The DRMG theme *supporting coordination and synchronization of distributed operations* is therefor highly relevant. Mastering the capabilities within the theme enables the organizations to manage its adaptive capacity. The *sharing information on roles and responsibilities* capability card was chosen as relevant for adaption to the case. This was due to the nature of the contract model that is considered in the case, where a supplier provides the drone and the operation of it. The other capability cards within the theme could also be of interest, but where not considered do to the time limitations of the thesis. To adapt the triggering questions of this capability card, the stakeholder analysis and the FRAM were helpful.

As mentioned in section 4.1.1 the stakeholder analysis revealed the need for coordination and management of the various players and their expectations for the operation, a coordination that can be vital for ensuring successful operation and help reduce the risk of conflicting goals. The analyzes show that the there are multiple actors involved in the operation, that require coordination both internally, between the departments and externally, between the actors. The coordination of the actors involved is somewhat easier in everyday operation than in crisis as the roles and responsibilities are easier defined. However, due to the coordination of multiple actors, the questions related too roles and responsibility can help reveal aspects that could strengthen the collaboration between the actors, and improve the ability to act and adapt.

The FRAM performed in section 4.1.3, also reveal a need for coordination between the actors. The functions in the model are color coded based on who they belong to. This show the interface between the two actors, and also show where communication and collaboration is necessary. The division of roles and responsibilities affect how decisions are being made, and how the operation is performed. The pentagon analysis identifies possible challenges related to the functional structure of the organization. Roles and responsibilities and authority are factors that affect procedures, requirements and decision making in the operation. These again are important for the successful performance of the operation.

Based on the findings, triggering questions related to the degree of involvement of actors, coordination mechanism, impact on organization when changes are made, internal dissemination of changes, and the division of responsibilities between operator and drone was chosen. Of particular interest was the division of responsibilities between the actors, and how the activities being performed are coordinated. To consider the degree of involvement, and reveal division of responsibilities between the two organizations, a scenario was provided for the subjects to reflect on how decisions would be made in such a scenario. The development and responsibilities in regards to procedures and plans for the operation was a focus in the adapted questions.

In crisis management there will exist many sources of resilience. A lot of preparation is put down in case of an event, to be as prepared as possible. In these plans there will be instructions and procedures on how to act, resources ready for use, monitoring of situations, a mapping of dependencies and interactions that could lead to possible propagation of effects, and systems for learning from and training for such events. There will also exist sources of brittleness. Not everything can be planned, and where extra resources could exist in one situation, they could lack in another. Crisis are also often subject to lack of information, as there are many uncertainties in relation to these events. With many actors involved, goal conflict could occur. The systems could be less prepared than wanted, and end up constrained or fall victim to bottlenecks. All these could contribute to difficulties to adjust when the crisis hits. The DRMG theme *Assessing resilience* seeks to identify both sources of resilience and brittleness. These two capabilities were also chosen as relevant for the case operation. While uncertainties are smaller for the everyday operations, as explained in 2.7.2 variabilities in the operation are unavoidable. Knowing the sources of resilience allows for strengthening of these, and improving the resilience. Identifying brittleness allows the organization to address these, and implement actions.

Choosing the triggering questions for the *identifying sources of resilience* capability, it was first considered what topics could be of interest for the operation. Then the most fitting questions within the topics where adapted. The pentagon analysis, FRAM and literature review all reveal aspects of interest regarding possible sources of resilience.

The FRAM identifies monitoring of the operation as a possible source of resilience. The oil company has a monitoring function in the FRAM. This function ensures that the operation is going to plan, and following procedures. It allows the company to aid in the operation if necessary. The model also shows that data is being collected and transferred for storing during the operation. This also presents an opportunity for monitoring. This opportunity was also identified by the literature review, highlighting the opportunity of gathering large amount of data using sensors on the drones. If the important data is extracted, this could be applied to learn from the operation. Triggering questions where therefor chosen to create reflections concerning monitoring, both how data could be collected and treated, as well as what could be learned from the data.

Another possible source of resilience that was identified by the FRAM, and also in the pentagon analysis, is the capability to learn. In the FRAM one of the functions is an *after work review*. A method like this allows for run through of the operation after it has been performed, where both things that went good and bad could be addressed. This would secure learning form ones failures and successes. In the pentagon analysis learning is pointed out as an opportunity related to the culture of the organization. Ensuring that there is a culture for taking in the lessons learned after each operation would be a source of resilience. Triggering questions related to the ability to learn was therefore chosen.

Another possible source of resilience identified is the procedures, strategies and plans the company applies in order to perform operation successfully, and to be able to adapt in the face of changes. The literature review highlights the importance of mission planning, and anticipating challenges before starting the operation. The review also revealed potential methods to strengthen the planning of the operation. Procedures, plans and requirements are also identified as part of the formal structure of the organization. The FRAM has planning of the operation as a function in the model. Procedures are also in the model as a background function that provides input to the planning. The plan dictates the performance of the operation, and can be an important tool to ensure the operation is successful. Triggering questions related to possible strategies, procedures and methods, as well as the possibility of already existing strategies, procedures and methods to be applied in the operation, was chosen and adapted to the case.

The importance of having resources available is also seen in the FRAM. Both human, technological and operational resources are of importance for the success of the operation. Technical components throughout the system must function for the functions in the model to be performed without variability. In the literature review specifically the technical resources have been identified. Having backup solutions for drones, sensors, and communication are discussed. The pentagon model also identifies various resources throughout the organization as possible opportunities or challenges. Triggering questions regarding available resources in the operation, and the coordination of these was therefor chosen. While available resources constitutes a source of resilience, lack of resources would constitute brittleness. This is further discussed below.

Lastly, a triggering question related to interactions and dependencies was chosen. It can be seen in the pentagon analysis and the FRAM that the system consists of many components, and that there will exist dependencies and interconnections that could possibly lead to propagating effects through the system. Reflection on these connections, and possible ways variabilities could affect other parts or functions of the system is important for the resilience of the operation.

For the *Noticing brittleness* capability a similar approach was made. The most relevant topics where chosen based on findings from the analytical methods, and the most fitting questions were chosen. The pentagon analysis, FRAM and the literature review all revealed possible challenges and weaknesses that could affect the resilience.

While the analyses have identified possible available resources that would constitute a source of resilience, lack of such resources would be a brittleness. In FRAM the same resources that would be a source of resilience, could also cause variabilities that affect other functions if the resources are lacking. The FRAM identifies human, technological and organizational resources that all have to contribute for the success of the operation. Lack of any of these could cause variabilities, and reduce the resilience capability. Lack of resources was also identified as a challenge by the literature review, specifically related to technical components of the system. Communication networks and links are identified as vulnerable, and should as such have back-ups. The battery life of the drones is also highlighted, and could cause loss of drone if there are no extra resources available. Like for the sources of resilience, questions related to the resources was therefore chosen. Here the focus is on possible situations where resources are lacking, how the lack of resources could be avoided, and where resources could possibly be added.

Another source of brittleness that shows up in the analyses is possible constraints and bottlenecks. The literature review points at constraints related to battery life of the drone, communication with the drone, the range and mobility of the drone and the operating environment. Also the pentagon analysis has identified some possible constraints on the system, specifically related to technical parts of the system, and the humans in the operation. Questions were chosen for reflection over possible constraints and bottlenecks, and how they affect the actors involved and other operations. Goal conflicts is identified by the pentagon analysis as a potential challenge for the operations. These could be internal or external. Questions identifying possible goal conflicts, as well as priorities when goal conflicts occur was chosen from the triggering questions.

Lastly, a question related to lack of information was added. The operation is new, and will therefor be subject to lack of information as there is no experience from such operations. The lack of information could in the startup phase of the operations affect the procedures and plans for the operation, as there will be aspects that there is no or little information about. The question added is to create reflections around possible brittleness based on information from similar operations, that could cover some of the knowledge gap in the new operation.

There are three phases to a crisis; before, during and after. As presented in 2.8.1, each capability card is therefor divided into three categories; Before, under, and after operations. Due to the scope focused on everyday operation, and this being a new operation, the focus in the thesis has been on the category *before crisis*. However, many of the triggering questions chosen and adapted could be applied in the context of during and after operation. As the operation is not yet being applied, there was no opportunity to test questions for during or after operation. The first attempt at adapting the guidelines have an interview guide of 29 triggering questions for the three capability cards. The next step in the adaption is to test these question to see if they can stimulate reflections and evaluations that could be applied to improve the resilience capability of the operation. This is further discussed in the following section.

5.2 Application of the DRMG

This section is focused on the application of the DRMG. The adapted triggering questions where tested through a set of interviews. The results from the interviews are presented i section 4.2. The test conducted show that applying the triggering questions stimulates reflection and evaluation of the operation among the leaders. Many of the reflections made could be applied to strengthen the resilience of the operation, this thorough strengthening of already existing sources of resilience, or implementing measures to reduce the brittleness. This can be seen by DRMG-map in figure 2.14, where the capabilities of *identifying sources of resilience* and *noticing brittleness* provide input to the *Enhancing the capacity to adapt* capability.

the testing of the triggering questions gave some interesting reflections on the capabilities by the subjects. Among the topics with the most rewarding answers was monitoring, learning, difficulties to adjust, lack of resources and involvement of organization.

Monitoring is one of the cornerstones of resilience, and this was therefor one of the topics addressed by the triggering questions. As can be seen in table 4.11, the subjects had interesting reflections on the data that is collected in the operation, and how the useful data could be extracted. There are also reflections on how data like this could be applied for learning, both now and with a future perspective. In table 4.13 the subjects were questioned about learning from what goes well. Here they reflect on the importance and usefulness of such a capability, but also reveal that this is something they are not particularly good at. They can only show to methods and tools related to learning from things that go wrong. It reveals a huge potential for using big amounts of data that are usually passed by when only focusing on learning from things that go wrong. As explained in 2.7.2, the frequency of things that go right is much larger than of what goes wrong. The reflections on these topics could prompt the action of systems or methods for learning from what goes wrong, and ways of extracting and applying useful data gathered in operations. This is further discussed in section 5.3

In table 4.14 the subjects have addressed brittleness as a result of lack of resources. Here, the subjects identify the potential of various resources presenting a problem in the operation. One subject also reflects that a possible reason for this could be the organizations focus on lean thinking. One drawback of the lean methodology is that it leave little room for deviations and errors. The lack of resources could stop an operation from starting in the first place, or reduce the systems ability to rebound if events occur during operation. The reflections made could allow for planning of extra resources where necessary.

Through the questions on roles and responsibilities, the subjects get to reflect over the coordination and collaboration with the supplier who performs the operation. Understanding their role, and the shared responsibilities in the operation, is important to facilitate the operations ability to adjust. In table 4.20 the subjects reflect on the importance of identifying events where parallel operations or other events might require communication and collaboration on how the organization involved will interact. They also suggest that priorities should be established, where both actors involved should know how to act in certain events.

While the test show that applying the triggering questions is a plausible method to generate reflection that could be used to prompt actions to improve resilience, some of the questions give better results than others, and there is a potential for improvement of the adapted questions. There could be different reasons why some of the questions more successfully triggers reflection;

- Understanding of resilience concepts to facilitate relevant reflections.
- The wording of the adapted questions, and the information given.
- Missing knowledge and information regarding the operation, as it is still in the development phase.

While the interview subjects have in depth knowledge of and experiences from the industry, and similar operations, most of them gave the impression that they are less familiar with the concept of resilience. To set the scene for the interviews, some information was given for the subjects to prepare themselves, the information can be seen in appendix D. This information is not sufficient for the subjects to properly obtain the knowledge required to fully understand the capabilities of their own operations. Obtaining this knowledge is the first step in the process of both *identifying sources of resilience* and *noticing brittleness*. As such, for the best result of application of the triggering questions, managers who are to apply them needs to build their own skills. Lack of understanding of resilience will lead to insufficient reflections, that do not help achieve the expected results of applying the capability cards.

The lack of understanding of the resilience concept was expressed by some of the subjects during the interviews, and shows in some of the answers to the questions. This is particularly the case for the questions regarding *noticing brittleness*. There are times where the subjects do not identify brittleness, under the opinion that these problems are dealt with through traditional safety management. An example is quoted in table 4.14. One subject reflects that lack of resources is a problem that happens quite often, but that it will not become a problem. During an operation lack of resources will not be a problem because if resources are missing the operation will not be performed as dictated by safety and risk management. This reveals a lack of understanding of the principle that variabilities could occur during operation that the safety management methods can not predict. Thus, the reflection does not lead to an evaluation of what resources could problematic, and the possibility that lack of resources might require further measures. The same understanding can be seen by a quote in table 4.19. The subject from environmental surveillance suggests the use of safety and risk analysis in the work of reducing differences between WAI and WAD.

The wording of the adapted triggering questions and the information given out before the interviews also affects the subjects reflections. The questions where adapted to fit to the case, and were also translated to Norwegian to be more understandable for the subjects. The questions could lose their meaning, or adapt another meaning if this is not done correctly. An example of this can be seen in question 4.3.4 in the interview guide in appendix K. While the original question in English is meant to uncover whether there is any information about similar operations that could help uncover brittleness, the translated Norwegian question has taken on another meaning. This question now asks if there is any sources of information from similar operations that could be used to cover the lack of information in the new operation. Rather than using existing information to uncover brittleness, this question now reveals possible sources of resilience rather than brittleness.

Some of the questions are formulated to be leading. Normally, in interviews this kind of question would be avoided to avoid false or slanted results. However, as these are triggering questions they are meant to trigger certain reflections on specific themes. Questions like 4.2.4 on training of personnel, 4.2.7 on monitoring and 4.2.12 on learning from what goes well, are formulated to make the subjects reflect on resilience capabilities, and away from traditional safety thinking. As explained above, the questions regarding learning and monitoring both provide interesting reflections that could be applied, and the leading nature of the questions therefor fulfilled its purpose, rather than mislead the subjects.

Information on the case, with some examples, was sent out to the subjects to prepare for the interviews. As the operation is in a starting phase, it became necessary to provide some context for the subjects. However, this information might have been to leading, causing the subjects to lose some reflections, and get attached to examples and information given. This can be seen from the answers in table 4.5. Here the subject where asked about possible strategies that could be applied to handle sudden loss of capacity, or increase in demands during an operation. The answers reflect that the subjects chose to answer for the example of loss of capacity given in the information that was sent out as a preparation, that contact with the drone is lost. This gives reflections of usable strategies for some cases, but misses many variabilities that could occur. The information given when applying the triggering questions should therefor be revised and changed to avoid this effect. This can also be avoided when the subjects are more familiar with the operation, as the information will not be needed. The issue of uncertainties regarding the operation is discussed following.

The operation that constitute the case of the thesis is still in the design and development phase. Due to this, there are varying understanding among the subjects regarding how the operation will look when implemented. The subjects come from different backgrounds, and while some of them have directly worked with the development and implementation of the operation, others come from a user stand point, and has other expectations. The difference in knowledge and expectation shows in how some of the subjects have contradicting or differing answers to some of the triggering questions. This contradiction and difference might also appear not just where the understanding is different, but where none of the subjects have information. During the interviews one of the subjects expressed; *Of course, it is a step in development to pull the operation onshore, and especially when you start to cut this umbilical cord, to make these drones more or less autonomous, then we have little, direct experience with it.*

One subject addressed by the triggering questions that show contradictions and differences in answers, is related to resources. There are varying opinions on presence of competency from the oil company during the operation. In table 4.9 one of the subjects considers that there must be someone accompanying the operation 24 hours a day. To contradict this, another subject states in table 4.8 that a 24/7 support network is not possible. Further, in table 4.10, one subject highlights that coordination between the actors need to be close, whether the oil company follows the operation from their own offices or from the control room of the supplier. However, the other subjects express the opinion that such follow up will not be necessary, and that the coordination and collaboration can be performed how similar operations are performed today. The biggest differences between the answers for this subject is most likely related to the subjects background. The subject that has worked with the development of the operation and the technology has a more preservative look, concluding that the coordination with the supplier has to be close due to the nature of the operation being subject to many uncertainties. The subjects who consider that the operations will look somewhat similar to existing operations, come from a user standpoint, and only has an understanding of how the operations would be applied, and what tasks they would perform.

Another subject that show a range of different opinions, is that of dependencies and interactions. Here we see some differences based on the subjects understanding of future developments of the operations. Table 4.12 shows that the subject who is working with development of UID technology consider problems related to dependencies and interactions as a consequence of the future development where it is possible that UID docking stations are shared between different actors. This is not information that all the other subjects consider, as they are not aware of this future opportunity. Considering their knowledge of the operation as it will look in the beginning, they consider more local dependencies between drone system and the hydro carbon systems they will operate on.

The subject of goal conflicts show some contradicting opinions among the subjects. While some point to possible conflicts due to multiple use of drone, or poor contract model, one of the subjects considers that goal conflicts will not be a problem as there would not be much strain on the use of the drone. Again, it might seem that the subjects have answered with different time perspectives in mind, or different contract models for the drones. Starting up the operations, and clarifying contract models and possible future developments would reduce the conflicting answers. It should be noticed that sometime conflicting answers like these could divulge issues in themselves. Managers should be on the same page regarding the operation and how they are performed, regardless of what department they belong to.

Another consideration to make in the application of the triggering questions is how to involve all the actors. As the operations are performed by a supplier, the results include reflections regarding sources of resilience and brittleness in the suppliers operation. It is important that the suppliers have the same resilience thinking, and that they operate according to the correct principles to ensure that measures based on reflections made by applying the triggering questions have the intended effect.

To optimize the effect of applying the triggering questions, the subjects should be educated on resilience, the operation should be better defined and understood the same by all the subjects, and as shown in figure 5.1, the questions should be revised after they are tested. The first adaption of the triggering questions was not perfect, and new adaption and correction would be necessary. Due to the one hour time limit on the interviews, some questions were prioritized. These are marked with stars in the interview guide in appendix K. These would need testing, and further revising like the other questions. However, due to time limitations revision of the questions falls outside the scope of the thesis. This is further discussed in section 6.2.

The triggering questions have only been applied once, and are in need of revising to optimize their usefulness. Even when the triggering questions have been revised, and a set of triggering questions is completed, further revisions might be necessary if there are changes in the operation. As such, there will never be a final set of revised questions that would not need changes. In a longer time perspective, applying the triggering questions should be done as a part of a continuous resilience management process, similar to other management processes applied in the company. A suggestion for such a continuous process was presented in section 4.1.2, and can be seen in figure 4.3. The process suggested fits well with what the adaption and testing of the triggering questions have shown us. To start with, an understanding of resilience must be developed in the organization. This can be done by seeking out theory and other work on resilience. Next, applying the DRMG and the triggering questions would cover the steps *Guidelines and framework for resilience* and *assessing where resilience is needed* in the figure. The next step is to implement actions and measures to improve the resilience. The last step is to monitor and assess the resilience. The two last steps are further discussed in the following section. If the resilience management is to have a lasting effect, the process through the figure needs to be repeated continuously. The resilience management thinking should be applied through the entire organization, and not only for the operation. This way, resilience thinking could develop to become a part of the organizational culture and values, how safety I thinking is today. This kind of transition in way of thinking and acting would not happen over night, but require work and dedication from the organization.

5.3 Implementation of measures and actions

For the reflections and evaluations made using the triggering questions to have any effect on the resilience of the operation, actions need to be implemented and followed up. The application of the triggering questions can reveal areas where actions are required. The testing of the questions showed this. Among other things it was revealed that while the potential for learning from things that go well is big, there are no systems or methods in place for this. It was also revealed that a lot of data can be gathered during the operations. If the important data can be extracted from all this data, the organizations ability to monitor would be strengthened. Potential brittleness in the operation was revealed, in form of lack of resources, possible goal conflicts, constraints and bottlenecks and deviations from plans and procedures. A need for close coordination and collaboration with supplier was also identified.

Possible actions that could be implemented for the operation based on the subjects reflections from the testing could be;

- **Creating and implementing systems and methods for learning from what goes well.**
    - o Systems for reporting of actions and decisions made that contributed to the success of the operation. This could be used as input for improving procedures and plans, or in training of other personnel.
    - o Before, during and after work reviews.
- **Building sufficient buffer of the most crucial resources.**
    - o Ensuring available expertise through training of more personnel
    - o Backup for technical systems like drones and communication links
- **Providing means to deal with conflicting goals**
    - o Ensure contract that reduces the possibilities of goal conflicts at the suppliers
    - o Establish prioritization for use of drone
- **Ensuring procedures and plans are updated based on experiences of successful operation, through use of triggering questions**
- **Creating indicators that extract the important data, and can be used to monitor and assess the resilience.**
    - o Indicator to show improvements as a result of successful operation
    - o Indicator showing weighs the relation between learning from success and learning from failure
- **Dealing with uncertainty due to operation being new by benchmarking with other industries or operations.**

As mentioned, the triggering questions could be applied for the different phases of the operation, before, during and after. Using questions specifically for the different phases could create reflections and evaluations on the resilience that is related to the specific phases, and thus actions and measures for the specific phases could be worked out. Questions directed toward the before phase could specifically help the operation to be better prepared, and the questions directed at the after phase are focused on learning from what has been experienced. However, there will still be variations in the during phase, no matter how much preparation and learning the company achieves. Questions directed at the during phase can thus create reflections and evaluations on how to deal with these unknown variabilities when they occur.

Using the questions for all phases require that the operations is active, and that more information is available. As the operation is still in the development and test phase, this is not possible to perform yet. However, applying the triggering questions in the development phase could be a good way to implement resilience as a part of the design of the operation. This would allow actions and measures implemented in the design to be tested in early phases of the operation. This could reduce cost of implementing the measures, as compared to doing so at a later stage.

Another thing to consider with the implementation of actions and measures based on the triggering questions, is what actors the measures will affect. The stakeholder analysis in section 4.1.1 identified internal and external stakeholders in the operations. The measures and actions will affect various departments in the oil company, and also various external actors. Mainly, the suppliers that provide the service of performing the operations would be affected by these. If the actions and measures are to have effect, the external stakeholders have to understand and apply them correctly. For example, the operator of the drone would have to participate in the after work review, and for this experience sharing and learning to have effect, the operator would have to understand what was learned so that it can be applied in the operation.

Implementation of actions is outside the scope of the thesis, but the examples give here shows how reflections and evaluation made when applying the triggering questions from DRMG, could give input to the development of actual actions. These measures, if used correctly could help in the improvement of the resilience capability of the operation.

Chapter 6

Conclusion

The objective of this thesis was to adapt a chosen set of capability cards for application in the case operation. The thesis set out to answer the following problem statement;

- *How can the DRMG be adapted and applied to improve resilient management for remote operation in the petroleum industry?*

Through the thesis a set of triggering questions from the DRMG where adapted, and application of the questions where explored through a set of interviews. The results show that the triggering questions can stimulate helpful reflections and evaluations that could be used as input for the development of measures and actions, that when implemented could help improve the resilience capability of the operation. The adaption was made for a specific case, and the resulting questions might therefor not be generalizable for other operations. However, the method of adapting the DRMG for application could be applied for other operations and processes to form triggering questions applicable for various cases. The results also show that the triggering questions adapted in the thesis would need to be revised for them to have the optimal effect. With this, it can be concluded that the success criteria and expected results listed in section 1.4 were achieved.

The use of the DRMG has to be implemented into an already existing quality system for planning, during or after action review. Applying the guidelines should be a part of the continuous work on improvement of the operation, where utilizing the triggering questions to gain new reflections and evaluations should reiterate. The DRMG suggest that the outcome from applying the guidelines can be utilized to revise internal guidelines, procedures and training, or to create new guidelines for the specific purpose. As such the guidelines will be implemented in governing documents and training programs in the organization to be utilized in planning and performing operations. One way of doing this could be to implement the triggering questions as a part of an after or before work review. This can facilitate discussions and reflections on things that go well.

The guidelines should be applied by leaders in the operation, both from the oil company and contractors. As discussed, leaders who are to apply the guidelines and capability cards also needs training and education to gain the skills needed to understand resilience concepts, and as such identify sources of resilience and brittleness in their own operation. If it is difficult for existing leaders in the company to take on this task, external experts could be utilized. The new resilience practices have to be combined with existing practices. As mentioned in section 2.7.2, adopting a resilience perspective does not mean that all existing practices are discarded, but that a new perspective is applied for those practices. This also affects how the results are interpreted. The resilience practices should be combined with the traditional risk evaluation and barrier approach that is traditionally applied in the industry. This is further discussed in section 6.1.

The DRMG are originally developed for crisis management in aviation and health care. Through this thesis the opportunity of adapting the triggering questions for management of everyday operation has been explored. The results show that it is possible to apply the guidelines for this purpose, and revision of the guidelines could be made to incorporate this kind of application. This would expand the scope of the guidelines, and there would be many new possible scenarios and industries that could utilize the guidelines. Everyday operation is much more common than crisis scenarios, and applying resilience management at this stage could reduce the probability of crisis scenarios occurring.

Applying resilience management for this operation, and possibly other operations would have various implications for the industry. These are further divulged in section 6.1. This thesis only adapted a chosen set of capability cards to one specific case. How this work can be further developed is considered in section 6.2.

6.1 Implication for the Industry and Case

The new concept of underwater drones could have many positive effects for the industry. Performing tasks in hazardous areas not accessible by humans, with a higher degree of efficiency and availability than the current operation models applying ROVs from the platform or a vessel. Having the drones live on the seabed reduces the need for deploying the drones from the surface, and reduces the effects of weather and sea condition on the operations. Further it removes the need for control rooms and operators on the platform or on the vessels, as the remote control of the UIDs is thought to be performed from an onshore control room. As the drone solution is further developed, it could be applied for a range of task, like inspections of installations, environmental surveillance or intervention and repair of components. Standardizing solutions for the docking stations, these could be placed out and utilized by different fields and different companies. The UID operations could reduce costs related to personnel, but also resources needed in the operation. The integrated operations approach explained in section 2.3, is helpful in facilitating use of new technology, and cross organizational communication. However, due to the new nature of these operations, there is also many uncertainties and knowledge gaps. In addition, there is an increase in complexity and interrelations in systems and organizations. This is where resilience management could be applied.

As mentioned in section 2.6, the resilience capability is believed to have the potential to address increasing complexity, and deal with the dependencies and interconnections in modern systems and operations. It is also addressed how the oil and gas industry through their extensive barrier strategies have increased the complexity of their own systems. Implementing the use of resilience management could be a way for the industry to help deal with complexity, while also relieving some of the complexity caused by the barrier layers.

To be able to apply resilience management in the same capacity as the traditional safety management, a big change in safety thinking and culture is necessary. The safety I related management methods and tools have been developed and applied for many years, and have become an integrated part of the industries safety work. To implement resilience management and safety II thinking the organization needs to obtain knowledge, experience and capabilities related to resilience. As discussed in section 5.2, establishing resilience management could take time. It would be necessary for the resilience management process to be applied as an continuous improvement process to obtain desired effects. The DRMG could be applied as a guide to resilient management in the industry. They should be applied in a continuous process, as the one suggested in figure 4.3. A change like this needs to be implemented throughout the organization, and become a part of company culture.

If resilience management is implemented alongside the traditional safety management, the potential for learning and understanding ones operations and processes will be greater. As shown in figure 2.13 in section 2.7.2, applying resilience management would consider all possible outcomes, from positive to negative. As mentioned in the section, the normal outcomes are much more frequent than things that go wrong, and as such constitutes a much bigger foundation of data that could be monitored. The data can be applied as input for learning, which finally aids the capability of responding to expected and unexpected events. By applying resilience management the organization could enhance its capabilities to anticipate, monitor, learn and respond, and advance toward becoming a system of the fourth kind, as defined in table 2.3.

6.2 Further Work and Opportunities

The thesis set out to adapt a set of triggering questions from the DRMG to the case in question. The effect of the resulting set of adapted questions was further explored through interviews, and the method for adaption and testing has been discussed in chapter 5. As concluded, the triggering questions seem to have the desired effect when tested, however it is also shown that some of the questions are in need of revision to work as intended. Furthering the work of this thesis, the questions chosen for the operation could be revised and retested to optimize the questions for application. In addition to revision of questions, it is revealed in the discussion that the subjects that were interviewed were in need of a better understanding of the resilience concepts. If the DRMG are to be applied for the operation, it will be required that the leaders are educated on this.

Only a chosen set of capability cards where considered in the thesis due to time limitations. The method utilized for adapting the capability cards in the thesis could further be applied to other capability cards if relevant. This could for examples be for the *enhancing adaptive capacity* capability, which is an important capability if the goal is for the operation to advance towards being a system of the fourth kind. The information basis utilized to chose and adapt questions could also be improved when the operations start, and experience and knowledge is gathered. The analyses made could be performed with more accuracy, and actual input based on operations. This would also improve the subjects understanding of the operation, which would lead to less differences in answers due to differing understanding of the operation.

In the test application of the questions, they were applied in a *before operation* context. As there are different phases of the operation, the questions could also be altered and tested for a *during*

operation and *after operation* context. This would have to be performed after the operations have started. Reflecting on the questions in another context could reveal new aspects of the resilience capabilities that are more prominent in the other contexts. Another possible furthering of the thesis work, is trying to adapt triggering questions to other cases and operations in the company. Optimally, resilience management should be applied throughout the organization, and not only for specific operations. In the long run, it could be possible to try and create an industry-specific catalog of triggering questions context trivialized for multiple operations and processes. Making the questions more generic could be easier if the organization improves their knowledge and skills related to resilience, as specific examples and cases would not be needed to convey the meaning of the questions. More emphasis could be put on exploring paradoxes that surface through the application of the triggering questions, and what these reveal with regards to the operation in a resilience management perspective.
The thesis focuses on the *guidelines and frameworks for resilience* and *assessing where resilience is needed* steps of figure 4.3. The next steps of the figure concerns implementation of actions, and monitor performance. Furthering the work of the thesis, the reflections and evaluations made applying the triggering questions could be utilized to identify possible actions and measures, and consider the implementation of these. To monitor the effect of the actions and measures, indicators could be developed to monitor the resilience performance of the operation. Changes in performance could be applied as input to revise the triggering questions if needed. As the resilience management is to be a continuous process, a new round of applying the triggering questions from the DRMG could be performed after the new actions and measures have been in use for a period of time. This work would require a longer time frame than what the master thesis has available. It would also require that the operations have started, and that indicators have been made and applied to evaluate the initial state of resilience in the operation.

The thesis presents diverse building blocks, an ecosystem of actors and analytical methods, that can be further enhanced and used to reflect on everyday operations. The FRAM model could be expanded to cover different types of inspections, and could also change according to different contract models. This would give different possible instantiations that could be further explored to reveal more variabilities. Relevant people could also be involved in the analysis, with more experience and knowledge regarding the operation. The pentagon analysis could be performed with attention to different organizational departments within the company, and also closer consider the relation between the oil company and the suppliers. The suggested model of using resilience management as an element to deal with the organizational aspects could be further investigated, and implemented into the analysis. The literature review could be expanded to consider more relevant elements of drone operations, allowing the organization to learn from other industries and their experiences.

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Appendix

A. Email From the PSA

Hei

Viser til deres spørsmål i e-post av 30.9.2019 angående Petroleumstilsynets regelverk knyttet til landbaserte kontrollrom som benyttes for styring av ubemannede innretninger.

Dagens rettstilstand og myndighetsfordeling
I de tilfeller hvor kontrollrom på land er lokalisert på landanlegg, jf. rammeforskriften § 2 jf. § 6 bokstav e), faller disse i sin helhet inn under Petroleumstilsynets tilsynsmyndighet. Petroleumstilsynet vil da kunne føre tilsyn med disse med hjemmel i petroleumsloven, arbeidsmiljøloven og brann- og eksplosjonsvernloven (med tilhørende forskrifter).

Bildet blir mer komplisert når kontrollrom som styrer innretninger på sokkelen plasseres på land i alminnelige kontorbygg eller lignende – uten tilknytning til landanlegg. Slike tilfeller aktualiserer spørsmål om forholdet mellom petroleumsloven og arbeidsmiljøloven, og den korresponderende fordelingen av tilsynsansvar mellom Petroleumstilsynet og Arbeidstilsynet.

På sokkelen har Petroleumstilsynet ansvaret for HMS- oppfølgingen av petroleumsvirksomheten både i henhold til petroleumsloven og arbeidsmiljøloven. På land er det imidlertid Arbeidstilsynet som håndhever arbeidsmiljøloven med underliggende forskrifter. For kontrollrom på land har Petroleumstilsynet altså ikke myndighet til å håndheve arbeidsmiljøloven eller Petroleumstilsynets særlige forskriftskrav fastsatt med hjemmel i arbeidsmiljøloven - de arbeidsmiljømessige forholdene vil falle under Arbeidstilsynets regelverk og myndighetsområde. Men når aktørene velger å organisere sin petroleumsvirksomhet ved å gjennomføre deler av denne på land, vil de deler av landvirksomheten som er nødvendige for forsvarlig virksomhet på sokkelen fortsatt falle inn under petroleumslovens krav til sikkerhet og forsvarlig virksomhet - og dermed inn under Petroleumstilsynet myndighetsområde i henhold til petroleumsloven. Petroleumstilsynet kan derfor føre tilsyn med relevante landfunksjoner som er sikkerhetskritiske for virksomheten på sokkelen, med hjemmel i petroleumslovens bestemmelser om sikkerhet og forsvarlig virksomhet. Derav følger at Petroleumstilsynet også kan håndheve relevante krav i HMS-forskriftene på de aktuelle landfunksjonene, så langt disse forskriftskravene er hjemlet i petroleumsloven.

Når det gjelder hvor langt Petroleumstilsynet kan gå i å stille krav til landfunksjoner med hjemmel i petroleumsloven og underliggende forskriftskrav, er utgangspunktet at det kan stilles krav til forhold som etter en påregnelig årsakssammenheng kan få betydning for virksomheten på sokkelen, og som har potensial for at funksjonssvikt kan føre til direkte sikkerhetskonsekvenser.I en del tilfeller vil det kunne være glidende overganger og overlapping mellom sikkerhetskrav med hjemmel i petroleumsloven, og arbeidsmiljøkrav, slik at det vil bero på en konkret vurdering om krav i sokkelregelverket kan rettes mot funksjoner på land. Petroleumstilsynet og Arbeidstilsynet arbeider derfor aktivt for et konstruktivt og koordinert samarbeid i tilsynet mot kontrollrom som er lokalisert på land (utenfor landanlegg, jf. rammeforskriften § 2 jf. § 6 bokstav e).

B. Review Protocol

Background

This review is performed as part of a master thesis. A research will be conducted to develop an overview of existing material on use of drones in various industry, and to map challenges and opportunites. The thesis is focused on the field of safety managment of remote operations, specifically Resilience Engineering, and is a continuation of a project thesis conducted in advance of

Research questions

A literature review will be conducted as part of the data collection, to improve the understanding of drone operations. A set of focused research questions have been formed to aid the development of search terms and strings:

RQ1: How does various industry approach comunication in operations of drones?
RQ2: How does various industry approach solutions for docking and charging in drones?
RQ3: How does various industry approach execution of mission planning?

The information collected through the litterature search will be used to compare and learn from from experience from other industry.

Search strategy

Based on the research questions and the PICOC (Population, Intervention, Comparison, Outcomes and Context), search terms can be defined. Synonyms for the search terms must also be considered. These search terms can then be combined into the search strings used in the review. The search will be performed in english and norwegian. The following terms and strings have been choosen for the review;

Search terms

English	Synonyms	**Norwegian**	Synonyms
Drone(s)	Mobile robots, ROV(s), UID(s)	Drone(r)	Mobile roboter, ROV, UID
Operation(s)		Operasjon	Drift
Communication		Kommunikasjon	
Industry use	Industrial use, Industrial application	Industrielt bruk	
Industry		Industri	
Docking	Docking station	Docking	Dockingstasjon
Charging	Charging station(s)	Lading	Ladestasjon(er)
Mission planning		Oppdragsplanlegging	
Execution(s)		Utførsel	Gjennomføring

Search strings	
English	**Norwegian**
(("drone" OR "drones" OR "mobile robots" OR "ROV" OR "ROVs" OR "UID" OR "UIDs") AND ("operation" OR "operations") AND ("communication") AND ("industry use" OR "industrial use" OR "industrial application" OR "industry"))	(("drone" OR "droner" OR "mobile roboter" OR "ROV" OR "UID") AND ("operasjon" OR "drift") AND ("kommunikasjon") AND ("industrielt bruk" OR "industri"))
(("drone" OR "drones" OR "mobile robots" OR "ROV" OR "ROVs" OR "UID" OR "UIDs") AND ("docking" OR "docking station") AND ("charging" OR "charging station" or "charging stations") AND ("industry use" OR "industrial use" OR "industrial application" OR "industry"))	(("drone" OR "droner" OR "mobile roboter" OR "ROV" OR "UID") AND ("docking" OR "docking stasjon") AND ("lading" OR "ladestasjon" OR "ladestasjoner") AND ("industrielt bruk" OR "industri"))
(("drone" OR "drones" OR "mobile robots" OR "ROV" OR "ROVs" OR "UID" OR "UIDs") AND ("mission planning") AND ("execution" OR "executions") AND ("industry use" OR "industrial use" OR "industrial application" OR "industry"))	(("drone" OR "droner" OR "mobile roboter" OR "ROV" OR "UID") AND ("oppdragsplanlegging") AND ("utførsel" OR "gjennomføring") AND ("industrielt bruk" OR "industri"))

Sourses to be Searched
I) Scopus II) Web of Science
Study selection criteria
To determine which studies to included in and exluded from the litterature review, the following study selection criteria have been defined; Inclusion: Material published from January 2015 and discribe relevant use of drones in industry cases. And the abstract of the material must contain the topic of the search question. The litterature will also be limited to literature that we have access to. The thirty most relevant articles will be choosen for analysis. Excluded material: Material written in languages other than english and norwegian will be exluded from the search. Also, anly material not covered in the choosen search resorces will be exluded. Only material written the last five years will be included, and any material written before the year 2015 will therefor not be included in the search. If any material is found in more than one of the resourses, the most complete version will be used.
Study selection procedures
A search will be conducted for each search string, in the selected databases. All result will be recorded in an excel document. Here information like author, title, publication year, key words and abstract will be documented. The results will be evaluated by the students conducting the search, applying the study selection critera. First the papers will be split in half and evaluated by one of the students. In the forst round the papers will either be included, excluded, or set as *maybe.* The papers set as maybe will then be evaluated by the other student, to decide wether the paper is included or not, if there are not enough articles set as yes. This will strengthen the quality of the data collection. Any further dissagreements will be documented in the final report with the use of Cohen Kappa statistic. The dissageement will be discussed and resolved by the support of the study selection criteria consistency, a re-evaluation, contacting the authors in question for further information, or guidance from the supervisor.
Data extraction strategy
The data collection will then be analysed in Excel. Where more information might be necessary, the papers can be further scrutinized. Primarily the introduction and conclusion of papers will then be considered. The analysis will consist of a content analysis. Findings will be visualized through use of different diagrams and tables, to map out the key findings of the material.

C. Search Log

Search String	Database	Pilot Search/ corrections made	Number of articles found	After exclusions -language -year -article type -not books
I	Scopus	No corrections made	English: 76 Norwegian: 0	English: 35 Norwegian: 0
II	Scopus	No corrections made	English: 18 Norwegian: 0	English: 15 Norwegian: 0
III	Scopus	No corrections made	English: 24 Norwegian: 0	English: 16 Norwegian: 0
I	Web of Science	No corrections made	Search made with given time limit	English: 7 Norwegian: 0
II	Web of Science	No corrections made	Search made with given time limit	English: 0 Norwegian: 0
III	Web of Science	No corrections made	Search made with given time limit	English: 0 Norwegian: 0
I	Recurring literature: 4 Total: 38			
II	Total: 15			
III	Total: 16			
Total number	69			

D. Interview information for subjects

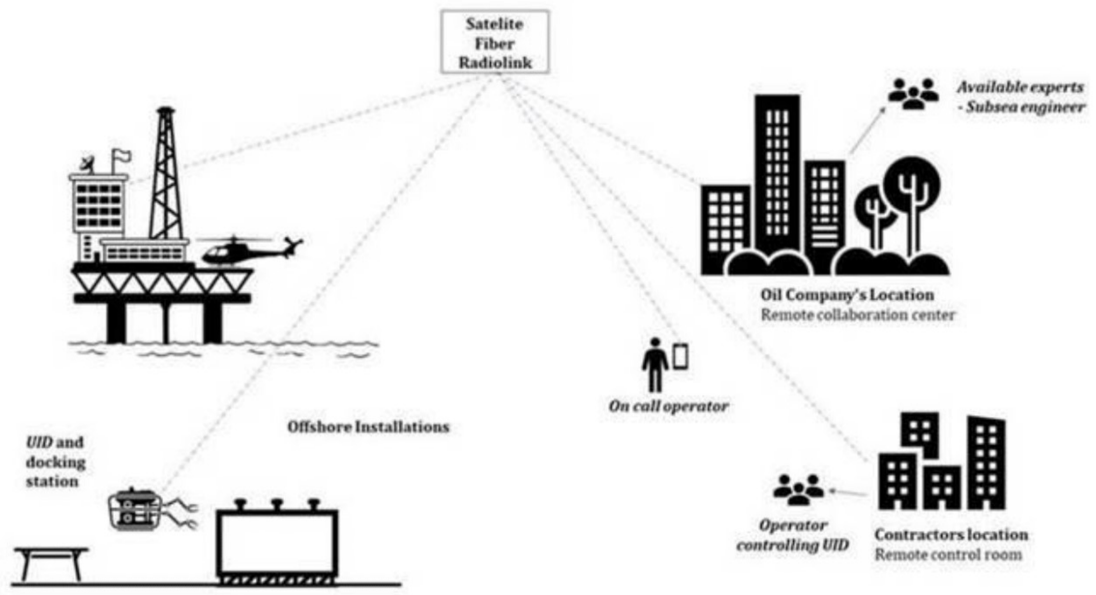
Information in Norwegian

Informasjon

Intervjuet er relatert til bruken av UID-er (underwater inspection drone) til inspeksjons operasjoner på undervannsinstallasjoner, under driftsfasen av et olje- og gassfelt. UID-ene vil "bo" på havbunnen, og ha en dokking stasjon for å lade og motta operasjonsdata (planer). Følgende kontrakts modeller vurderes;

1. Inspeksjoner av topside- (platform, vindmøller etc) og undervanns- installasjoner kan planlegges på forhånd, og forhåndsprogrammeres. Droner eies og drives av entreprenør, og kan kontrolleres fra entreprenørens kontrollrom, som ligger på land. Planlegging av oppdrag og utførelse, gjøres med godkjenning fra oljeselskapet.
2. Kontroll- og rapporterings operasjoner gjennomføres. Disse initieres ved behov for å verifisere teknisk tilstand av forskjellige komponenter eller systemer. Disse operasjonene kan ikke planlegges på forhånd, og startes basert på mistanke eller alarm (bruk av sensorer) angående den tekniske tilstanden. Disse operasjonene utføres med droner leid inn av oljeselskapet, og kontrolleres av operatører fra kontrollrom som ligger på land i oljeselskapets lokaler.

Vi skal se vurdere en case hvor en UID er satt til å utføre et planlagt inspeksjonsoppdrag på en undervannsinstallasjon. Under operasjonen går kommunikasjonen med dronen tapt. Figuren under viser aktørene som er involvert i/under operasjonen.



Spørsmålene er relatert til operasjonens Resiliens (motstandsdyktighet). I engineering sammenheng er resiliens definert som systemets evne til å motstå og komme tilbake til starttilstand etter en forstyrrelse. Resiliens antas å ha potensial til å adressere den økende kompleksiteten i dagens systemer og organisasjoner. Resilience engineering bør forstås som evnen til å operere på en resilient måte, ikke som en egenskap.

Spørsmålene er basert på tre kapasitetskort fra DARWIN resilience management guidelines (DRMG), og tar for seg *Sources of Resilience*, *Brittleness (skjørhet)* i operasjonen og *Roles and responsibilities*.

- Spørsmålene om *Sources of Resilience* har som mål å identifisere metoder, strategier og prosedyrer som bidrar til at organisasjonen lykkes med å håndtere forventede og uventede forhold.
- *Noticing Brittleness* spørsmålene ser etter variabiliteter, og sammenligner Work-as-intende (WAI) med work-as-done (WAD), dette for å avdekke hvordan systemet kan operere med større risiko enn forventet. Dette kan avdekke muligheter for å investere i korreksjoner og forbedringer.
- Spørsmålene om *Roles and responsibilities* gir en forståelse av hvordan roller og ansvar er delt mellom de forskjellige aktørene som er involvert i ledelsen og utførelsen av operasjonene. Dette innebærer å forstå de interne rollene og ansvarene, så vel som eksternt med tanke på organisasjoner som samarbeider i operasjonen.

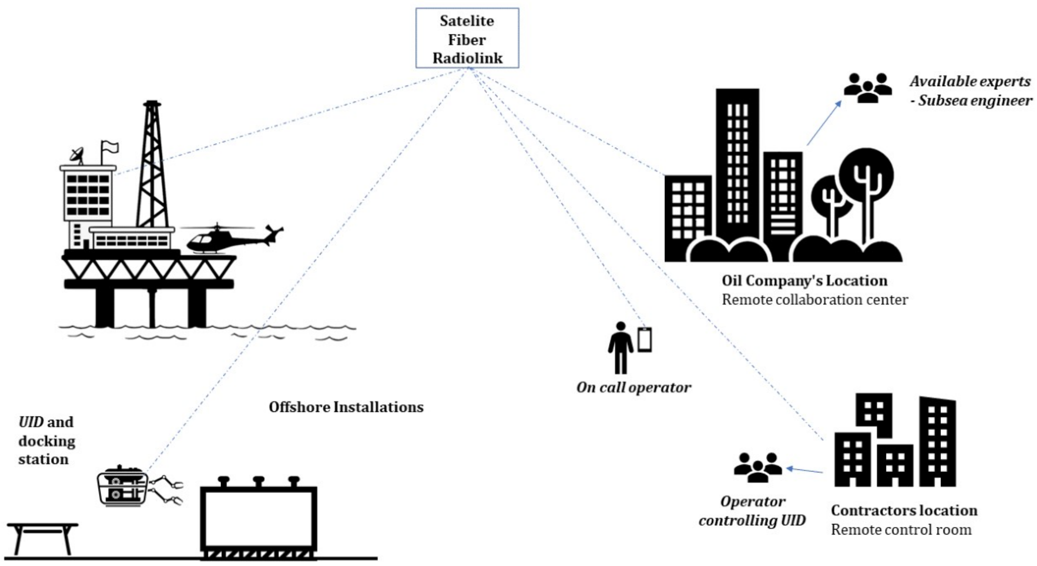
Information in English

Information

The interview is related to the use of UIDs for inspection operations on subsea installation, during the operation phase of an oil and gas field. The UIDs will "live" at the seabed and have a docking station for charging and receiving mission plans. The following contract model is considered;

1. Inspections of topside and subsea installations can be preplanned, and preprogrammed. Drones are owned and operated by contractor, and can be controlled from contractors control room, situated onshore. Mission planning and execution is done with approval from the oil company.
2. The check- and report- operations are initiated when needed, to verify technical condition of various components or systems. These operations cannot be preplanned, and are initiated based on suspicion or alarm regarding the technical condition. These operations are performed with drones owned by the oil company, and are controlled by operators from control room located onshore at their offices.

Consider the case where an UID is set to perform a planned inspection mission on a subsea installation. During the operation, communication with the drone is lost. The figure below shows the actors involved in the operation.



The questions are related to resilience of the operation. In the context of engineering, resilience is defined as a systems ability to withstand and return to initial state after a disturbance. Resilience is believed to have the potential to address the increasing complexity. Resilience engineering should be understood as the capability to perform in a resilient way, not as a property.

The questions are based on three capability cards from the DARWIN resilience management guidelines, and addresses *Sources of resilience*, *Brittleness (skjørhet) in operations* and *roles and responsibilities.*

- The *Sources of resilience* questions have as a goal to identify methods, strategies and procedures by which the organization successfully handle expected and unexpected conditions.
- The *Noticing Brittleness* questions looks for *variabilities* and compares *work-as-imagined* with *work-as-done*, this to reveal how the system might be operating with bigger risk than expected. This can uncover opportunities to invest in corrections.
- The Roles and responsibilities questions gives a understanding of how roles and responsibilities are divided between the different actors involved in the management and execution of the operations. This involves understanding the internal roles and responsibilities, as well as externally with organizations that are collaborating in the operation.

E. Statement of Consent

Do you want to participate in the research project "DARWIN Resilience Management Guidelines for Remote Operations"?

This is a request for you to participate in a research project where the purpose is to adapt DARWIN guidelines for resilient remote control operations of underwater drones. In this paper, we provide you with information about the goals of the project, and what participation will mean for you.

Purpose
DARWIN Resilience Management Guidelines were developed under HORIZON 2020, the EU's research project to strengthen the EU's position in research work. The purpose of the project is to adapt guidelines to strengthen existing procedures, guidelines and routines for remote control of underwater drones. The project is a master thesis carried out by two students within health, safety and environment at NTNU.

Who is responsible for the research project?
The Department of Industrial Economics and Technology Management at NTNU is responsible for the project.

Why are you asked to participate?
The selection was made on the basis of company and occupation, where available suppliers of solutions and services relevant to the case have been contacted.

What does it entail for you to participate?
If you choose to participate in the project, it entails that the students will send a questionnaire.

Participation is voluntary
Participation in the project is voluntary. If you choose to participate, you may withdraw your consent at any time without giving any reason. All information about you will then be anonymized. It will not have any negative consequences for you if you do not want to participate, or later choose to withdraw.

Your privacy - how we store and use your information
We will only use the information about you for the purposes we have stated in this letter. We treat the information confidentially and in accordance with privacy policy.

- Two master's students and their supervisor will have access to the information
- Names will be replaced with a code stored on their own name list separate from other data (Name only used for signature)

Participants can not be recognized in the publication, as the purpose of the interview is to map the work processes and operations. Only information about the work processes and operation will be published.

What happens to your information when we finish the research project?
The project is scheduled to be completed on June 11, 2020. Data from the survey will then be destroyed.

Your rights
As long as you can be identified in the data material, you are entitled to:
- insight into what personal data is registered about you,
- getting personal information corrected,
- get personal information about you deleted,
- obtain a copy of your personal data, and
- submit a complaint to a Data Protection Official/Officer or the Data Protection Authority regarding the processing of your personal data.

What gives us the right to process personal information about you?
We process information about you based on your consent.

On behalf of the Department of Industrial Economics and Technology Management at NTNU, NSD - Norwegian Center for Research Data AS has considered that the processing of personal data in this project complies with the privacy regulations.

Where can I find out more?
If you have questions about the study, or wish to exercise your rights, please contact:

- Ivonne Herrera, associate professor at the Department of Industrial Economics and Technology Management, NTNU. Ivonne.a.herrera@ntnu.no
+4790680634
- NSD - Norwegian Center for Research Data AS, by e-mail (personverntjenester@nsd.no) or by phone: +47 55 58 21 17.

With best regards

Ivonne Andrade H (signature) | Emilie Låstad | Charlotte Hjelmseth Larssen

Projectmanager (Researcher/supervisor) | Students

Statement of Consent

I have received and understood information about the project "DARWIN Resilience Management Guidelines for Remote Operations of Subsea Drones", and have had the opportunity to ask questions. I agree to:

- To participate in a survey

I agree that my information will be processed until the project is completed, approx. June 11, 2020.

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(Signed by project participant, date)

F. Classification of Stakeholders

Classification of internal stakeholders	
Central technology environment	
Power	***Influential***
	The oil company's central technology environment sits on knowledge and experience valuable for the project and operation. Assets that will be used in the development of the operation.
Attitude	***Backer***
	The central technology environment will contribute to the development of the UID operation, and is therefor likely to have a backing attitude.
Interest	***Active***
	The internal stakeholders in the oil company's will be directly affected by the change in operation, and will therefor have a strong interest in the project and the operation.
Classification	***Savior***
Operation center	
Power	***Insignificant***
	The development of the operation is conducted by the development department. And the operation center have minimal power within this development.
Attitude	***Backer***
	The operation center is likely to back the project gaining improvements such as improved response time for check and report operations.
Interest	***Active***
	The internal stakeholders in the oil company's will be directly affected by the change in operation, and will therefor have a strong interest in the project and the operation.
Classification	***Friend***

License user/owner	
Power	***Insignificant***
	The society have power over the project and the future development of operations.
Attitude	***Backer***
	The project and operation is likely to save cost and time, key factors for these actors.
Interest	***Passive***
	These actors will have a passive role in the development of operation.
Classification	***Sleeping giant***

Classification of external stakeholders	
Suppliers of docking stations	
Power	***Influential***
	The power of suppliers towards the operation depend on their marked position. If there are many suppliers to choose from the power of the suppliers decrease. Another factor is to what degree it is possible to switch between suppliers after startup of the operation, and the cost related to this. In the process of startup of the operation there are different suppliers to choose from, but the suppliers will contribute to the development of the new operation, but will have little power and the suppliers of docking stations will therefor have power over the project and the operation.
Attitude	***Backer***
	The suppliers have a backing attitude towards the project and the developed operation, with the potential for sale of their product or service.
Interest	***Active***
	The suppliers main priority is to sell their products, therefor they have a strong interest in the project and the further development of the operation. Also, the technology is new, holding potential for further improvements beneficial for the suppliers development of product.
Classification	***Savior***

Suppliers of UIDs	
Power	***Influential***
	The power of suppliers towards the operation depend on their marked position. If there are many suppliers to choose from the power of the suppliers decrease, and vice versa. Another factor is to what degree it is possible to switch between suppliers after startup of the operation, and the cost related to this. In the process of startup of the operation there are different suppliers to choose from. But the suppliers will take part in the development of the operation, and the remote operation of the UIDs. Therefor the supplier will have influence over the development, and might be difficult to switch out over time.
Attitude	***Backer***
	The suppliers have a backing attitude towards the project and the developed operation, with the potential for sale of their product or service.
Interest	***Active***
	The suppliers main priority is to sell their products, therefor they have a strong interest in the project and the further development of the operation. Also, the technology is new, holding potential for further improvements beneficial for the suppliers development of product.
Classification	***Savior***
Suppliers of infrastructure	
Power	***Influential***
	The power of suppliers towards the operation depend on their marked position. If there are many suppliers to choose from the power of the suppliers decrease, and vice versa. Another factor is to what degree it is possible to switch between suppliers after startup of the operation, and the cost related to this.
Attitude	***Backer***
	The suppliers have a backing attitude towards the project and the developed operation, with the potential for sale of their product or service.
Interest	***Active***
	The suppliers main priority is to sell their products, therefor they have a strong interest in the project and the further development of the operation. Also, the technology is new, holding potential for further improvements beneficial for the suppliers development of product.
Classification	***Savior***
Media	
Power	***Insignificant***
	Media have little influence over the project and the operation.
Attitude	***Backer***
	Media is likely to back the project. But have the potential to turn in the meeting with events that sheds a negative light on the project or the operation.
Interest	***Passive***
	Media have minimal interest in the project and the operation as of today, but events that sheds light on the operation might change their profile over time.
Classification	***Acquaintance (With the potential to become a trip wire)***

Government/Regulators	
Power	***Influential***
	The government and regulators have influence over the project and the operation by existing and the development of relevant laws and regulations.
Attitude	***Backer***
	This actor have a financial interest in the energy production, Also, this actor have an interest in technological development, increasing the countries competitiveness within future energy production.
Interest	***Active***
	The operation require an adaption of existing laws and regulation, that the government and regulators will need to develop to meet the new operation.
Classification	***Savior***
NGOs	
Power	***Insignificant***
	Non-Governmental Organizations have insignificant power over the development and the operation.
Attitude	***Backer***
	NGOs is likely to back the project. But in the event of environmental challenges or loss of workplaces due to the change in operation, environmental or social beneficial NGOs might gain interest in the change of operation.
Interest	***Passive***
	NGOs is likely to have a passive interest towards the project. But in the event of environmental challenges or loss of workplaces, environmental or social beneficial NGOs might gain interest in the change of operation.
Classification	***Acquaintance (With the potential to become an irritant)***
Universities/Research	
Power	***Influential***
	Universities and research facilities have experience valuable for the development of the project, and will take part in the project.
Attitude	***Backer***
	These actors have an strong interest in a collaboration with the company and its project, and will therefor back the project and the development.
Interest	***Active***
	Universities and research facilities holds an active role in the development.
Classification	***Savior***
Society	
Power	***Insignificant***
	The society have little to minimal power on the project and the future operations.
Attitude	***Backer***
	The society is likely to back the project and operation.
Interest	***Passive***
	These actors will have a passive role in the operation as long as no events shed light on the operation.
Classification	***Acquaintance***

G. Strategy for Handling of Stakeholders

Purposes strategies based on Murray-Webster and Simons classification scheme	
Central technology environment	
Savior	Saviors is actors key to the project and the operation, due their power, interest and positive attitude. Murray-Webster and Simons recommend to pay attention to these stakeholders, and keep them on the supportive side. The central technology environment will take a part of the development, and the main strategy should therefor be focused on keeping them supportive.
Operation Center	
Friend	Friends are actors backing and having high interest in the project and the operation, but with little power. The purposed strategy for these actors are to use them as sounding board, to utilize their interest and knowledge regarding the remote operation.
License user/owner	
Sleeping Giant	Sleeping Giants are passive influential backers, and Murray-Webster and Simon purpose that sleeping giants should be involved to fully utilize their full potential. The purposed strategy is to turn this actor into a savior, by gaining their interest for the project and operation.
Suppliers of equipment and infrastructure	
Saviors	As the central technology environment the suppliers of equipment and infrastructure are actors important to the project and operation, that should be held attention too and kept supportive.
Media	
Acquaintance (with the potential to become a trip wire)	Actors recognized as acquaintance have a low degree of interest and power towards the project and operation, but have a backing attitude. Due to the low degree of power and interest these stakeholders should be kept informed on a need to know level.
Government/Regulators	
Savior	Just as the the central technology environment and the suppliers of equipment and infrastructure are actors important to the project and operation, the government and regulators should be held attention to and kept supportive of the project and operation.
NGOs	
Acquaintance (Whit the potential to become an irritant)	NGOs are actors holding the same profile as media, and should be provided with information on a need to know level.

Universities/Research	
Savior	The universities and research facilities are key actors for the project and operation, sitting on knowledge and experience valuable for the development. They therefor need to be held attention to, and kept supportive.
Society	
Acquaintance	Just as media and NGOs society holds the acquaintance profile towards the project and operation. And the society should therefor be provided with information on a need to know level.

H. Stakeholder Expectations

Identification of expectations and requirements of the internal stakeholders	
Central technology environment	
Basic	• Access to the amount of drones and charging systems needed to conduct the operations within an adequate response time
Performance	• A high influence over the choices made for the operation
Excitement	• Access to the newest technology and infrastructure • Limitless budget for renting/procurement of equipment and infrastructure
Operation center	
Basic	• Proper training and protocols for the new operation • Access to drones and resources when needed • Knowledge of the persons in charge and who to contact if needed • Stable network connection and UID communication • Reliable equipment and infrastructure
Performance	• Possibility to take part in the development of operation and protocols
Excitement	• Influence over the development and future work methods
License owner/user	
Basic	• Saving cost in future operation • Safe operation
Performance	• Improved response time
Excitement	• Positive recognition from external stakeholders • Free media publicity
Suppliers of UIDs	
Basic	• Communication with the company
Performance	• Collaboration with company regarding further technology development
Excitement	•Exclusive agreement with company regarding delivery of UIDs • Be included in the company's media publicity

Identification of expectations and requirements of the external stakeholders	
Suppliers of docking stations	
Basic	• Communication with the company
Performance	• Collaboration with company regarding further technology development
Excitement	• Exclusive agreement with company regarding delivery of docking stations • Be included in the company's media publicity
Suppliers of infrastructure	
Basic	• Communication with the company
Performance	• Collaboration with company regarding further technology development
Excitement	• Exclusive agreement with company regarding delivery of infrastructure • Be included in the company's media publicity
Media	
Basic	• Communication on a need-to-know level
Performance	• Access to information regarding the project and the operation
Excitement	• Exclusive collaboration with company with access for interviews/reports
Government/Regulators	
Basic	• Communication on a need-to-know level • Existing laws and regulations are being followed
Performance	• Collaboration on improvements of existing and development of new laws, regulation and standards
Excitement	• The company develop new and improve existing regulations, information shared with this actor.
Society	
Basic	• Communication on a need-to-know level • Safe operation • Existing laws and regulations are being followed • No loss of existing number of work places
Performance	• Safer operations due to improved response time • Safer work places for the operators due to • Safer work places for the operators and a reduction in the environmental footprint due to a lower number of operators traveling off shore
Excitement	• The development leads to a increased number of workplaces for the society • The project and operation leads to increased technological competitiveness towards other countries
NGOs	
Basic	• Communication on a need-to-know level • Safe operation • Existing laws and regulations are being followed
Performance	• Collaboration on relevant improvements/work
Excitement	• Support their work/agenda

Universities/Research	
Basic	• Communication on a need-to-know level
Performance	• Possibilities for collaborations with students and researchers
Excitement	• Creation of new research topic and work places due to the project and the new operation

I. Pentagon analysis for UID operation; Challenges and opportunities

Category of Organizational Variables	Elements	Challenges and opportunities
Formal Structure	• Organization of Oil Company (Top management, Department managers, Operators) • Organization of contractors • Roles and responsibilities • Authority • Procedures • Reporting • Requirements • Decision making	• Communication (external and internal) • Understanding roles and responsibilities • Complexity in organization • Inter-organizational collaboration • Conflicting interests/goals • Deviations from procedures • Poor decision making
Technology	• UID • Docking station • Sensors • Communication link (Fiber, Satellite, radio link) • Control room setup • Software • Power supply • Company Intranet/ cloud solution	• Communication loss • Communication delays • Cyber attacks • Failure of equipment (UID, sensors, CR setup, power supply) • Software error • Error in sensor data • Interdependencies and cascading effects • Interface between new and old technology • Gathering of data for improved learning • Machine learning • Efficient operation
Culture	• Values • Goals • Norms • Cultural understandings • Language • Human behavior • Expectations • Knowledge	• Conflicting goals • Misunderstanding • Unwanted behavior • Conflicts • Lacking or poor knowledge • Learning and experience transfer • Use of and understanding of technology • Situational awareness

Category of Organizational Variables	Elements	Challenges and opportunities
Interactions and work processes	• Department interactions • Control room interactions • Control center interactions • Interactions between operators • Interactions between contractor and oil company • Interaction with competitors	• Lack of / Poor / communication • Lack of / Poor collaboration • Lack of / Poor coordination • Improved communication, collaboration, coordination • Erroneous interpretations • Social effects • Human Behaviour • Learning from own and other organizations • Poor leadership/management • Co-opetition
Relationships and Networks	• Creating networks both internal and external • Informal relationships • Trust • Commitment • Competition • Alliances	• Lack of trust (collegues, management, technology) • Power struggle • Helpful alliances for inovation and creation of optimal solutions • Lack of commitment • Experience and knowledge transfer through formal and informal relations
External factors	• Environmental • Governmental • Societal • Economical	• Weather (Snow, rain, wind, fog) • Natural disaster • Currents • Waves ⇒ *Difficult operating conditions* • Regulations and classification • More cost efficient operation, but less jobs • Improved safety of workers • Greener operations • Competitors

J. FRAM Descriptions

Function	Function description	Aspects	Aspect description
Recognize need for inspection	This is a background function that initiates the activity of performing an inspection on a subsea installation. Recognizing the need for inspection could be based on condition data from the installation, or be based on a inspection schedule. The analysis has been limited to not look at these underlying functions.	Output	The output from this function is a notification that a inspection is needed, and that action should be taken. This notice would be forwarded to the correct department.
Planning Inspection	The responsible department receives a notification that their installation needs an inspection. A plan is then developed for the specific inspection. Procedures for the operation is used as a guide to develop the plan. The plan has to be forwarded to the operator contracted to perform the inspection, for reviewing.	Input	Notification of need for inspection. Can be sent through internal communication systems. The lessons learned from previous missions can also be applied in developing a new and improved plan.
		Output	Mission plan for the contracted operator. This will be forwarded to operator for reviewing after notifying of the need for inspection
		Control	Procedures for inspection. Sets guidelines and limitations for the inspection.
		Resource	The procedure could also be seen as a resource that helps develop the mission plan.
Contact Operator	When the notification of need for inspection is received, the operator should be contacted to request the inspection.	Output	A request for inspection from oil company. Mission plan should also be recieved following the request.
		Precondition	A need for inspection must exist
Reviewing plan	A request comes from the oil company to perform an inspection. Plan for the inspection is received, and this plan is reviewed to ensure the operator has an understanding of mission sequence. Reviewing the plan makes the operator prepared to perform the inspection.	Input	The mission plan from the oil company with guidelines for performing the operation. Should inform where and when the inspection is needed, what data is needed, and detailed program for the inspection.
		Output	The operator gets an understanding of the mission sequence, and can prepare for the inspection.
		Precondition	An inspection must be requested for reviewing of plan to commence.
		Control	The procedures for inspections sets guidelines for performing the inspection together with the mission plan. Operator must follow these.

Function	Function description	Aspects	Aspect description
Decision to start operation	The oil company and operator has to find a time for the inspection that fits the schedule of the operator, and does not conflict with other operations. Communication can happen over e-mail, phone, video calls or in person.	Output	Starting time for the inspection is set. Permission to commence with the inspection.
		Precondition	The operators should have reviewed the plan for the inspection before deciding on a time, as this informs them of the scope of the inspection.
Operating drone from control room	An operator from the contractor operates the drone through the inspection operation based on the plan provided from the oil company. The operator sends mission commands to the drone through a communication network.	Input	Mission sequence and information are obtained from the review of the mission plan. These are applied to form the mission commands. In addition the operator would apply lessons learned from previous missions to perform the operation successfully.
		Output	Mission commands for the drone. Communicated to the drone through wireless communication.
Maintenance	Background function that ensures that the drone is functioning as expected. Could be performed routinely, or based on the condition of the drone.	Output	Drone that functions at a desired level.
Start operation/ Contact drone	The drone is contacted and activated. As the drone is ”sleeping” in its docking station, it needs to be ”awakened” to commence with the inspection.	Input	Mission commands from operator.
		Output	Active drone. The drone can now continue to perform incoming commands.
		Time	The starting time for the operation is set in cooperation by the oil company and operator. The inspection cannot be performed outside planned time slots.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.
Monitor operation	Personnel from the oil company monitor the operation from their control center to ensure that the operation is performed according to plans and procedures.	Input	The received raw data from the mission (for example video, view of screens in the control room setup)
		Output	Regulation and guidance for the operation can be provided if necessary.
		Time	The start time of the monitoring is decided by the starting time set for the operation. End of mission is when the drone is back at the docking station and charging.
		Resource	The mission plan for the inspection can be utilized as a resource to evaluate the performance of the operation.

Function	Function description	Aspects	Aspect description
Drone moves to subsea installation	The drone must navigate from the docking station to the installation to be inspected. The drone could be controlled by operator, or navigate based on input of coordinates of the installation. Depends on how difficult the navigation is.	Input	Mission commands from the operator provide directions for the drone.
		Output	Drone will arrive at the subsea installation for inspection.
		Precondition	The drone needs to be active to navigate.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures
Perform Inspection of installation	The inspection has to be performed according to the plan. Parts of the installation that needs inspection has to be sought out. The drone needs to navigate the installation. This navigation is more critical than between the docking station and the installation, and requires more operator control.	Input	Mission commands from operator. Direct contact with drone to allow for real time navigation.
		Output	Drone present at parts of installation that require inspection, so that data can be gathered.
		Precondition	Drone has to be present at the installation before inspection can commence.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures
Gather data	During the inspection necessary inspection data and mission data has to be gathered. This is done by a range of sensors on the drone. This is data regarding the state of the installation, but also conditions of the mission and the drone.	Input	Information on what data should be gathered by what sensors. Ensure activation of sensors.
		Output	Various inspection and mission data.
		Time	The gathering of data has to happen in parallel with other activities during the mission.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.
Communicate/ transmit data	The data gathered has to be communicated to the oil company. This is done over wireless networks. (If not possible could be communicated when connecting to docking station?)	Input	Various data gathered by sensors on the drone.
		Output	Inspection and mission data arrive at oil company servers/ storage.
		Time	The communication has to happen in parallel with other activities during the mission to provide real time data.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.

Function	Function description	Aspects	Aspect description
Drone moves to subsea installation	The drone must navigate from the docking station to the installation to be inspected. The drone could be controlled by operator, or navigate based on input of coordinates of the installation. Depends on how difficult the navigation is.	Input	Mission commands from the operator provide directions for the drone.
		Output	Drone will arrive at the subsea installation for inspection.
		Precondition	The drone needs to be active to navigate.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures
Perform Inspection of installation	The inspection has to be performed according to the plan. Parts of the installation that needs inspection has to be sought out. The drone needs to navigate the installation. This navigation is more critical than between the docking station and the installation, and requires more operator control.	Input	Mission commands from operator. Direct contact with drone to allow for real time navigation.
		Output	Drone present at parts of installation that require inspection, so that data can be gathered.
		Precondition	Drone has to be present at the installation before inspection can commence.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures
Gather data	During the inspection necessary inspection data and mission data has to be gathered. This is done by a range of sensors on the drone. This is data regarding the state of the installation, but also conditions of the mission and the drone.	Input	Information on what data should be gathered by what sensors. Ensure activation of sensors.
		Output	Various inspection and mission data.
		Time	The gathering of data has to happen in parallel with other activities during the mission.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.
Communicate/ transmit data	The data gathered has to be communicated to the oil company. This is done over wireless networks. (If not possible could be communicated when connecting to docking station?)	Input	Various data gathered by sensors on the drone.
		Output	Inspection and mission data arrive at oil company servers/ storage.
		Time	The communication has to happen in parallel with other activities during the mission to provide real time data.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.

Function	Function description	Aspects	Aspect description
Drone return to docking	When the inspection is finished, the drone must return to the docking station. It has to navigate back the same way it navigated to the subsea installation.	Input	Mission commands from the operator provide directions for the drone.
		Output	Drone will arrive at the docking station for docking.
		Time	The drone must complete the inspection before returning home, unless it experiences low battery.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.
Drone docking	Drone has to connect to the docking station to ensure charging.	Input	Mission commands from the operator, to ensure good connection.
		Output	Drone connected to the docking station.
		Precondition	The drone must be present at the docking station to be able to connect.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.
Drone charging/ end of mission	The drone starts charging, and this ends the mission.	Input	Mission commands from the operator, to end mission. Drone goes back to "sleep".
		Precondition	Drone must be properly connected to the docking station in order to start charging.
		Control	The operation is monitored by the oil company to ensure it is performed in accordance to plans and procedures.
After work review	After the end of the inspection an after work review should be performed to run through all that went well, and not so well. In this way the organizations can gain lessons learned, and as such improve the operation.	Input	Based on the mission plan (WAI), and input of the inspection data, an after action review can be performed with the operator and the person who monitored the operation present.
		Output	When the after action review is performed, the organization gains lessons learned that can be transferred to the operators, and be applied in future planning of operations.
Receiving data	The data gathered during the mission is received in the oil company servers. The data is communicated wireless.	Input	Various data from inspection
		Output	Data from inspection in different categories
		Control	The operation is monitoring that data from the mission is being received.
Store data	The received data from the mission should be stored for further processing for different purposes.	Input	Different categories of raw data from the inspection.

K. Interview Guide

Interview Guide in Norwegian

Triggering Questions: Assessing resilience	
4.2 Identifying sources of resilience: learning from what goes well	
Before a crisis	
Adaptive capacity *The ability to adapt in case of sudden changes*	4.2.1 Hvilke strategier (arbeidsmetoder eller prosedyrer) kan benyttes til å håndtere plutselige tap av kapasitet eller økende belastning under operasjonen? (Kan være for check and report drone/ inspeksjons drone) (eg. UID not working, multiple possible faults to check for "check and report")
	4.2.2 Kan noen av disse (fra 4.2.1) strategiene/prosedyrene hentes fra andre lignende operasjoner? / Eksiterer det allerede strategier/ prosedyrer som kan benyttes (med små tilpasninger)? (Does the organization have procedures, strategies or planned responses applicable for the operation in question?)
	4.2.3 Ved hendelser hvor operasjonen avviker fra normal kan det være nødvendig å reorganisere roller og ansvar. Er dette noe det vil legges til rette for/ utarbeides prosedyrer eller strategier for? (Does the organization have any procedures or strategies for this?)
	4.2.4 Tror du personell som skal læres opp til slike operasjoner vil utsettes for situasjoner hvor det oppstår uventede hendelser og variasjoner som del av treningen? (Eg. Practice what to do if the drone doesn't respond)
Resources *Available resources in case of change in demand, and coordination of resources*	4.2.5 Hvilke ekstra ressurser (mennesker, teknologi, organisasjonelle) og alternative arbeidsmetoder vil være / bør være til stede? Hva gjøres for at personell skal være kjent med disse, og benytter dem? (Eg. Benytte muligheten for å kontakte kontrollsenter for ekspert hjelp, Backup Drones, alternative communication with drone etc)
	4.2.6 I casen er det flere aktører involvert. Hvilken koordinering mellom aktører er nødvendig med tanke på ekstra ressurser? (Avklarering av hva som finnes og hvem som skal stå for ressursene, hva krever f.eks oljeselksapet av back-up)
Monitoring *Monitoring of threats and successful operation*	4.2.7 Det er vanlig å monitorere forskjellige aspekter av prosesser og operasjoner. Hvilken monitorering kan man forvente ved en slik operasjon, og kan man benytte denne dataen til å lære om hva som gjør operasjonen suksessfull? (Monitoring things that go right (Eg. Mission data, Operation run through for operators) learning from things that go right?) (Asses changes)
Dependencies and interactions *Understanding of interconnections of operations, and*	4.2.8 Tror du det kan være potensial for kaskade/snøball effekter hvor små variasjoner i operasjonen kan kombineres, forplantes eller forsterkes gjennom systemet/organisasjonen?
	4.2.9 Hvor mye av operasjonen/ systemet må personell involvert i operasjonen ha kunnskap om for å vite hvilke effekter deres avgjørelser har? (In regards to how their decisions will affect other parts of the system)

understanding how variations can propagate through the system.	
	4.2.10 Hvordan bør man gå frem for å involvere alle relevante aktører slik at man kan fremme effektiv koordinering og unngå at det oppstår begrensninger/hinder for operasjonen? **(Før, under og etter operasjon)**
	4.2.11 Hvordan vil formelle og uformelle nettverk utvikles og ivaretas?
Learning *Ability to learn from things that go well/right*	4.2.12 En viktig del av resilience management er å lære av det som gjør at man lykkes. De foregående spørsmålene er ment for å identifisere evner/egenskaper strategier og prosedyrer som bidrar til at operasjonen går som planlagt. Hvilke metoder kan benyttes/ benyttes allerede til å ta lærdom av slike egenskaper, strategier og prosedyrer? (Learning from what goes well, rather than lessons learned from thing that go wrong) After work review – noe som overrasket (lære av det)
4.3 Noticing brittleness (Introdusere at det er nytt tema !!)	
Lack of Resources *Availability of Human, technical, material resources*	4.3.1 Kan det oppstå situasjoner hvor de ressursene (mennekser, teknologi, organisajonelle) man forventer er der ikke er tilgjengelig slik at man ikke får gjennomført operasjonen som planlagt? *Gi Eksempler* (Eg. No operator, no drone etc)
	4.3.2 Hvilke løsninger kan innføres for å lette/redusere belastninger på systemet? (How can the system be given a degree of slack? How can variabilities be reduced?)
	4.3.3 En mulighet er å øke systemets kapasitet. Hvor er det lettest å innføre ekstra kapasitet for å fjerne stressorer på systemet?
Lack of information *Availability of information necessary to perform operations*	4.3.4 Siden denne typen operasjonskonsept er ny, er det mange usikkerheter knyttet til manglende informasjon. Tror du informasjon/ erfaringen fra lignende operasjoner kan benyttes for å dekke noe av informasjonsmangelen, f.eks fra ROV/AUV operasjoner? (is there information available about similar operations that could help identify brittleness in the operation, and as such prepare/correct? Information available to operator/drone?)
Goal conflicts *Possible conflicts between goals within*	4.3.5 (Kan du tenke deg noen…) Vil det kunne oppstår målkonflikter (trade-offs) under operasjonen? *Gi Eksmpler* (Are the situations where goal conflicts can affect the operation or the safety of the operation? Contractor vs The oil company)

organization or between organizations	4.3.6 (og 4.3.7) Om slike målkonflikter skulle oppstå, hvordan vil prioritering etableres (prosedyrer/strategier)? Og vil det være mulig å gå bort fra eller redusere fokuset på et mål for å hindre slike konflikter (How are priorities made in situations where there is a goal conflict? What will be given most weight?)
Constraints and bottlenecks *Possible situations where system is constrained, or bottleneck occur as a result of workload*	4.3.9 Hvilke typer av variasjon/variabilitet kan ha potensiale til å utfordre systemets grenser? (Teknologi, menneske etc)
	4.3.8 Kan du også komme på slike situasjoner som kan hindre evnen til å gjennomføre operasjoner?
	4.3.10 Kan situasjoner der operasjonene fungerer som begrensning for andre organisasjoner oppstå?
Difficulties to adjust *Are there barriers to adjusting/ Adapting when needed*	4.3.12 Vil det være kapasitet for omplassering av eksisterende ressurser ved behov? Og hva kan forhindre dette? (Eg. Other operators in control room that have the skills required to take over)
	4.3.13 Basert på tidligere erfaring, vil et skille mellom offisielle prosedyrer og praksis kunne forventes? (WAI vs WAD, in experience is this a problem?)

Triggering Questions: Supporting coordination and synchronization of distributed operations	
2.3 Sharing information on roles and responsibilities among different organizations	
Involvement of organizations *How/ to what degree are different organizations involved in managing or operating*	2.3.1 Equinor har en check and report operasjon, leverandøren har en inspeksjons operasjon. Hva om disse skjer samtidig? Vil en felles prosedyre mellom de ulike aktørene utarbeides for å håndtere felles og parallelle operasjoner?
Coordination mechanism	2.3.2 Dersom en felles prosedyre vil utarbeides, vil en av organisasjonene være ansvarlige for denne, og en periodisk koordinering av aktivitetene med de involverte organisasjonene?
Impact on organization	2.3.3 Hvordan kan endringer I en av organisasjonene (leverandør/selskapet) påvirke rollene og ansvarsområdene i den andre organisasjonen?

Internal dissemination of changes	2.3.4 Dersom roller og ansvar i hos en av aktørene endres, hvordan vil relevant relevante informasjon og opplæring rundt dette bli gitt til personalet potensielt involvert?
	2.3.5 Dersom felles og parallelle operasjoner vil skje, hvordan vil kommunikasjonen mellom organisasjonene foregå?
HMT	2.3.6 I hvilken grad vil operasjonen være preprogrammert? Hvilke avgjørelser kan dronen gjøre, og når vil operatøren gripe inn?(Hvordan vil roller og ansvarsområder distribueres mellom operatøren og dronen?)

Interview Guide in English

Triggering Questions: Assessing resilience	
4.2 Identifying sources of resilience: learning from what goes well	
Before a crisis	
Adaptive capacity *The ability to adapt in case of sudden changes*	4.2.1 Which strategies (e.g. working methods or contingency procedures) can be used to handle a sudden loss of capacity and/or increase in demands during the operation? (eg. UID not working, multiple possible faults to check for "check and report")
	4.2.2 For which events (*unexpected/sudden changes/ variabilities*) are there an existing responses applicable? (Does the organization have procedures, strategies or planned responses applicable for the operation in question?)
	4.2.3 Will reorganization of existing roles and task be facilitated in response to such events? (Does the organization have any procedures or strategies for this?)
	4.2.4 Will the personnel be exposed to unusual and varying situations as part of the training? (Eg. Practice what to do if the drone doesn't respond)
Resources *Available resources in case of change in demand, and coordination of resources*	4.2.5 What back-up resources(human, technology) and alternative working methods will be available? And will the personnel be familiarized with these in order to readily use them? (Eg. Backup Drones, alternative communication with drone etc)
	4.2.6 What kind of coordination with other actors needs to be established regarding additional resources? (Requirements for backup solution from The oil company towards contractor?)
Monitoring *Monitoring of threats and successful operation*	4.2.7 What types of monitoring mechanisms will be put in place by the organization to anticipate and assess possible threats and opportunities? Will there be monitoring of operations that allow for learning from what goes right? (Monitoring things that go right (Eg. Mission data, Operation run through for operators) – learning from things that go right?) (Asses changes)
Dependencies and interactions *Understanding of interconnections of operations, and understanding how variations can propagate*	4.2.8 What strategies could be applied to foster a smooth coordination among actors, and minimize constraints and bottlenecks? (How are relevant actors involved (stakeholder strategies)?) Before action / After action (before, during, after)
	4.2.9 Which areas of the operation needs a bigger focus in regard to developing an understanding of the potential for small variations (in conditions and performance outcomes) to combine, propagate, and amplify across the organization (e.g "cascading", "butterfly" or "snowball" effects)? (Is there potential for-/ Where is the potential for cascading/snowballing effects in the operation?)

through the system.	
	4.2.10 What will the operators need to know about the other parts of the system they are interacting with? (In regards to how their decisions will affect other parts of the system)
	4.2.11 How will formal and informal networks, useful for handling potential crisis, be nurtured?
Learning *Ability to learn from things that go well/right*	4.2.12 The previous questions are meant to identify successful skills, strategies, and procedures. Are there any methods/approaches applied today for learning from these kind of skills, strategies and procedures? (Learning from what goes well, rather than lessons learned from thing that go wrong)
4.3 Noticing brittleness	
Lack of Resources *Availability of Human, technical, material resources*	4.3.1 Can there be situations in which the expected resources may not be available to perform the operation as planned? (Eg. No operator, no drone etc)
	4.3.2 What can be put in place to relieve, lighten, moderate, reduce and decrease stress or load on the system? (How can the system be given a degree of slack? How can variabilities be reduced?)
	4.3.3 Were do you think extra capacity could be added to remove stressors?
Lack of information *Availability of information necessary to perform operations*	4.3.4 Can you anticipate potential situations with uncertainty based on previous experience with ROV/AUV operations? (is there information available about similar operations that could help identify brittleness in the operation, and as such prepare/correct? Information available to operator/drone?)
Goal conflicts *Possible conflicts between goals within organization or between organizations*	4.3.5 Can you think of any potential goal conflicts and trade-offs? (Are the situations where goal conflicts can affect the operation or the safety of the operation? Contractor vs The oil company)
	4.3.6 (4.3.7)If such goal conflicts should occur, how will you establish priorities (procedures/strategies)? And how can the focus on one goal be reduced or removed in order to avoid goal conflicts? (How are priorities made in situations where there is a goal conflict? What will be given most weight?)

Constraints and bottlenecks *Possible situations where system is constrained, or bottleneck occur as a result of workload*	4.3.9 What types of situations do you think have the potential to push the system towards its limits during the operations? (What variabilities/ sudden changes might have the biggest potential to push the system?)
	4.3.8 Can you think of such situations that could hinder the ability to perform the operation?
	4.3.10 Can there be situations in which the operations act like a constraint for other organizations?
Difficulties to adjust *Are there barriers to adjusting/ Adapting when needed*	4.3.12 Will there be any capacity to relocate existing resources if needed? What may prevent this? (Eg. Other operators in control room that have the skills required to take over)
	4.3.13 Will major mismatches between official procedures and actual practices be expected? (WAI vs WAD, in experience is this a problem)

Triggering Questions: Supporting coordination and synchronization of distributed operations	
2.3 Sharing information on roles and responsibilities among different organizations	
Involvement of organizations *How/ to what degree are different organizations involved in managing or operating*	2.3.1 Will a shared procedure be developed between the different organizations required to manage operations jointly or in parallel? (The oil company has *check and report operations*, contractor has *inspection operations*, what if these happen at the same time?)
Coordination mechanism	2.3.2 When a shared procedure among different organizations exist, will there be one organization clearly appointed to activate and arrange periodic coordination activities with other organizations?
Impact on organization	2.3.3 How can changes in one organization (eg. suppliers/vendors) affect the roles and responsibilities in emergencies in the other organizations?
Internal dissemination of changes	2.3.4 Will adequate information and training on relevant changes of roles and responsibilities in other organizations be provided to the personnel potentially involved in the operations?

	2.3.5 Will a "quick reference guide" be developed to assist the personnel of organizations to promptly identify shared roles and responsibilities with other organizations in case of joint or parallel operations? (How is communication between the organizations in case of joint or parallel operation?)
HMT	2.3.6 How are the roles and responsibilities distributed between the operator and the drones? (To what degree is the operation preprogrammed, what decisions can the drones make, and when does the operator need to control/intervene?)

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DARWIN Resilience Management Guidelines for Everyday Operations in the petroleum industry

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