Master's degree thesis

LOG950 Logistics

Implementation of additive manufacturing technology as a risk mitigation and supply chain performance improvement strategy: A single case study of the Norwegian oil and gas industry

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Number of pages including this page: 99

Molde, 20.05.2022

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Abstract

The oil and gas industry has been, for many years, threatened by risks. However, they did not have the right tools to mitigate or strategically be prepared for these risks. Long lead times, requirements from stakeholders regarding reduced climate footprint, many suppliers, and a tremendous amount of money tied up in inventory have been their everyday life for many years. By implementing additive manufacturing technologies, including 3D printers and CNC machines on the base, some of the risks and uncertainties may be reduced or even deleted. In addition to risk reduction, this technology is also an excellent investment in their sustainable results both today and long term.

This master thesis will focus on *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within Norway's oil and gas industry.*

The originality of my research is the interaction in the supply chain and agreements with third-party businesses to find more risk-reducing and sustainable solutions to logistical procedures. The supply chain wants to increase performance with fewer risks, have less money tied up in inventory, and increase their sustainable performance now for the future. This master thesis is a single case study, and data are assembled from semi-structured interviews with important actors in this upstream supply chain. Secondary information is gathered through historical events, company reports, and research within Norway's oil and gas industry.

This thesis revealed that implementing additive manufacturing techniques is only a part of a more extensive supply chain plan. They will, in the future, have a circular economy where technologies play an essential role in all processes. Risk-reducing strategies, partnership, and vertical integration are all positive aspects of implementing such advanced manufacturing techniques. My future research suggestion is to investigate the effects of additive manufacturing. This master's was written early in the process of AM technology in this industry, and it would be interesting to follow this implementation through the whole process. Additive manufacturing technology cannot be implemented as the only solution to all their problems, but it will be a part of daily operations and future planning to decrease risks and the environmental footprint

Preface

This master thesis is a part of the requirements after finishing my two-year studies for the Master of Science in Logistics at Molde University College, Norway.

The final thesis represents independent, extensive research, which was created between July 2021 to May 2022 under the supervision of Associate Professor Bjørnar Aas.
Veronica Wichstrøm Rolland, Molde, 20.05.2022

Acknowledgment

This master thesis is the final and most memorable assignment of my two years at Molde University College.

Firstly, I would like to thank companies and personnel within the Norsea group, Transocean, and Wilhelmsen for making this project possible. Communication and interviews have provided me valuable information, data, thoughts, and plans. Without their time and effort, there would not have been enough information for this research, and I am incredibly grateful for their contribution and engagement in my thesis.

I would also like to express my gratitude to my supervisor Bjørnar Aas. Throughout the whole process, he has been supportive, honest and contributed valuable feedback and discussions through the whole master thesis process. Your knowledge of real-time situations within this industry, your sense of humor, and your relaxed approach have given me vital information and taught me to be patient.

Someone once told me that writing a master thesis is like participating in a marathon, but my methods for working are better described as a middle-distance run/sprint.
Lastly, I would like to thank my family and friends for their support and feedback. I could not have done this without you. Fellow students and writing buddies should also get credit for good memories throughout these two years and for being there as an emotional lighthouse in the last semester of this master's. It has been an honor working with all of you, and I am proud to announce that my grownup life is about to start.

Contents

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List of Abbreviations

3DP – Three-Dimensional Printing
AM – Additive Manufacturing
CAD – Computer-Assisted Design
CE – Circular Economy
CNC – Computer Numerical Control
ETO- Engineering-To-Order
GDP – Gross Domestic Production
JIT – Just-In-Time
MTO - Make-To-Order
NGO – Non-Governmental Organization
NSD – Norwegian Center for Research Data
OEM – Original Equipment Manufacturer
SC – Supply Chain
SCM – Supply Chain Management
SCRM – Supply Chain Risk Management
SERM - Sustainable Enterprise Risk Management
SSCM – Sustainable Supply Chain
SLA - Stereolithography
TBL – Triple Bottom Line
TCO – Total Cost of Ownership
TIR - Third Industrial Revolution

1 Introduction

In this part, I will present the background of the thesis, which includes information about a research gap and why it is essential to close this gap for several different stakeholders. I will then focus on the delimitations and prerequisites chosen to delimit the thesis to get a feasible solution to the research. The purpose of this research is clarified together with the research perspective. Lastly, I identify the structure of this thesis to get a clear view of how I have worked to answer the research question.

1.1 Background of the thesis

Ben Moussa et al. (2017, 2679) define supply chain management (SCM) as *"the planning and management of all activities involved in sourcing and procurement, manufacturing processes, and all logistics management activities, including coordination and collaboration with suppliers, intermediaries, third-party service providers, and customers.".* SCM is a newer extension phase of the old logistical phenomenon. This new concept has all of the functions of the logistics concept and relations, partnership, and cooperation with end-user and suppliers. Covey (1991, 7) concludes that *"the whole can be greater than the sum of its parts," which* means that stakeholder needs to be included or considered in the decision process. The reason is that they have an essential role in the success of an organization in today's environment (Freeman 2010, 24-25), and they need to be investigated to understand their willingness to inflate resources to either help or hurt the firm and SC (Freeman 2010, 26).

Handscomb, Sharabura, and Woxholth (2016) aid that oil and gas have been using a centralized supply chain structure. They also claim that the industry is in a process where they are changing more and more to a decentralized network, with minor but more locations around the Norwegian coast. They are also forced to rely on manufacturing strategies with shorter lead times and a lean strategy that maximizes the value of production and, at the same time, minimizes waste (Wilson 2010; Sundar, Balaji, and Kumar 2014). *"The best supply chains aren't just fast and cost-effective, they are also agile and adaptable, ensuring that all their companies' interests stay aligned" (Lee 2004, 1).* Additive manufacturing technology aims to reduce lead-time and cut total production costs, but it must ensure agility, adaptability, and alignment qualities to accomplish competitive advantage regarding sustainability (Lee 2004, 1).

The environmental focus has changed within management and operations to a broader view where optimization of environmental factors includes the whole SC. Discussions about sustainability result from this increased focus, and this has raised questions as to what to do today to ensure resources for future generations (Linton, Klassen, and Jayaraman 2007, 1075). One of the most used definitions of sustainability is using resources to fulfill today's needs without compromising the need for resources for future generations (Rosenberg et al. 1993; Gündling 1990). This definition, in modern editions, focuses more on scarce resources and shows concern about the distribution of wealth and businesses' social responsibility (Harangozó and Zilahy 2015, 19; Teuteberg and Wittstruck 2010; Mangla, Madaan, and Chan 2013).

Risk can be defined as "*the extent to which there is uncertainty about whether potentially significant and/or disappointing outcomes of decisions will be realized" (Sitkin and Pablo 1992, 2)*. Risks are primarily used in definitions together with the concept of uncertainty, which is referred to as unpredictable outcomes. Therefore, risks and uncertainty explain factors or situations that they cannot predict but need to consider when planning. In a planning process, decision-makers need to consider the internal uncertainties by searching for information and the external risks that need to be considered, such as buffers. Supply chain risk management (SCRM) is also a concept used to describe how to work with and manage risks that affect the supply chain (SC) and not only a single organization or link in the SC. This concept is more complex due to cooperation and collaboration between different organizations with different views, operations, and aims (Felea and Albastroiu 2013).

According to Spedding and Rose (2007) sustainability represents 12,5% of all risks within an organization. Sustainable risks are divided into economic, environmental, and social risks, like the triple bottom line. Environmental risks represent 5,4 percent of all risks, social and ethical risks represent 5,1 percent and economic and socio-economic risks are responsible for 2 percent of all risks within an organization and supply chain. Implementing a Sustainable Enterprise Risk Management (SERM) system connects sustainable risks to their risk strategy. This strategy includes reducing overall risks in the

SC, developing new solutions to products and services, improving their reputation and brand knowledge, and gaining more understanding from requiting (Spedding and Rose 2007). Risks and uncertainty are often related to negative consequences. Still, by focusing on how risks can be used to provide opportunities such as growth and gained knowledge risks, they can turn risks into something positive for the SC and the organizations within the SC (Bisson 2014; Spekman and Davis 2004, 416).

The oil and gas industry has reached a new epoch where new requirements from different stakeholders are changing along with changing environments. The nonrenewable energy provided by oil and gas will not last forever, and various actors in the original supply chain are changing to meet the needs in the future (Heum 2008, 7). Today, Norway relies heavily on oil and gas export; 42% of all export from Norway comes from the oil and gas industry. The income from this industry forms the Norwegian pension funds and ensures the social welfare of society (NorskPetroleum 2021b). Different actors have different focus areas in this implementation. Still, they all agree that AM technology might be a part of the solution to their problems or plan for future renewable energy sources. Approximately 10% of all components are profitable or possible to produce using this technology today, but this number constantly increases. These changes are a perfect opportunity to take a leading competitive position by making good risk management decisions, supply chain management decisions, and searching for sustainable solutions.

1.2 Research purpose

Shortcomings in the literature and interests in the changing environment in the oil and gas industry have motivated me to focus my master thesis on the research problem:
how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within Norway's oil and gas industry.

This master thesis presents an empirical case of the effects on a supply chain's overall performance regarding risk reduction and sustainability when implementing AM technology such as 3DP and CNC into their processes within Norway's oil and gas industry. Norsea will be the first offshore base using this technology in practice in Norway, and this is the reason for selecting them for this empirical case. There are information and literature on projects in other industries using this technology. Still, there is not much literature on Norwegian oil and gas organizations using it in their daily operations. Because of the early stage in the process, I can be a part of how this can be implemented and identify the possibilities in this market.

The three research questions this thesis will focus on to answer the research problem are:

1. How will supply chain management change after implementing AM technology?
2. How will AM be a technology that reduces risks in the supply chain?
3. What effects will this implementation have on supply chain performance?

This study has the main task of extending the research in this field by investigating literature on AM technology, especially 3DP from other similar areas, and supply chain management combined with the qualitative research methods used through a single case study. In addition to this, research on risk management and supply chain management within this industry will strengthen the research in this field. The study contributes to a deeper understanding and possibly gives them advice on focus areas in the implementation phase.

1.3 Structure of the thesis

This master thesis is divided into eight main chapters. The first chapter is the introduction with the theme and research question justification. Then the theoretical framework is presented in two parts to get an overview of available information related to supply chain management and risk management. The third chapter introduces the situation in Norway's oil and gas industry and available resources of AM technology that are not applied to their operations yet. Forth chapter is the methodology part; this is the part where choices are explained and a description of how this research has been completed. The fifth chapter is an introduction to the case. The data collected will then be presented in the findings chapter; this is where all obtained data from the different interviews are structured. Chapter number seven will discuss central findings, structured after the research questions presented in the introduction. Finally, findings are introduced to answer the research problem. The conclusion also includes the limitations of this research and suggestions for future research.

2 Theoretical framework

The theoretical framework will give an overview of existing theories within supply chain management and risk management to answer the research question: *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within the oil and gas industry in Norway.* First, I will start to present theories and concepts within supply chain management in today's competitive oil and gas market in Norway. The second theory this thesis will focus on is risk management, how to measure it, and how this can be an essential part of choosing projects to invest in.

2.1 Supply chain management within the oil and gas industry

2.1.1 Definition of supply chain management

There are several definitions of supply chain and supply chain management. Wong, Husain, and Sulaiman (2018, 72) defines supply chain management as: *"The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole."* SCM are also referred to as demand network management since it should be operated by market demand and not by suppliers (Christopher 2016). The term network by him is preferable because of the extent of supply chains today. Supply chains do not only include one supplier or one customer, but it has become a network of multiple stakeholders with interest in their operations. Ben Moussa et al. (2017, 2679) define supply chain management as *"the planning and management of all activities involved in sourcing and procurement, manufacturing processes, and logistics management activities, including coordination and collaboration with suppliers, intermediaries, third-party service providers, and customers."*

Supply chain management is a newer phase and is an expansion of the phase logistics. In addition to the logistical planning processes, the supply chain includes relations, trust, and cooperation to look at the whole network, from raw materials to the customer. Even though literature today argues that supply chain management is a new concept, there are sources and articles from way before supply chain management was a phenomenon that includes all parts and relations in the definition of logistics (Ballou 2007). Moreover, there are plenty of reports on supply chain management in the literature. Still, we can see a context in the different definitions by looking at the ones presented in this thesis. Supply chain management is a network between all supply chain links, including operational and relational.

2.1.2 Objectives of supply chain management in Norwegian oil and gas

2.1.2.1 Stakeholders' theory

Stakeholders are groups or individuals who affect or are affected by an organization's accomplishments. They, therefore, need to be considered whenever a change or a decision is made. As shown in Figure 1, these groups and individuals play an essential role in the success of an organization in today's environment (Freeman 2010). Different stakeholders have different levels of impact on the firm, depending on multiple factors, and therefore need to be considered differently. Because of the diverse needs of various stakeholders, a firm needs to map the critical issue for each stakeholder and their willingness to inflate resources either by helping or hurting the firm (Freeman 2010). Spedding and Rose (2007) put stakeholder assessment as a driver for results firms will have in the future.

There are different approaches to the stakeholder theory. Friedman and Miles (2006) describe them as normative, descriptive, and instrumental stakeholder theories. Normative stakeholder theory is related to managers' acts and views on the purpose of the whole organization, derived from ethical principles. The descriptive theory is used when there are concerns about how stakeholders and managers behave and how they observe their influence, role, and actions. The last view is formed upon the belief that if stakeholders are kept in line with a stakeholder concept, the organization will be more successful, and the ability for sustainability will be higher.

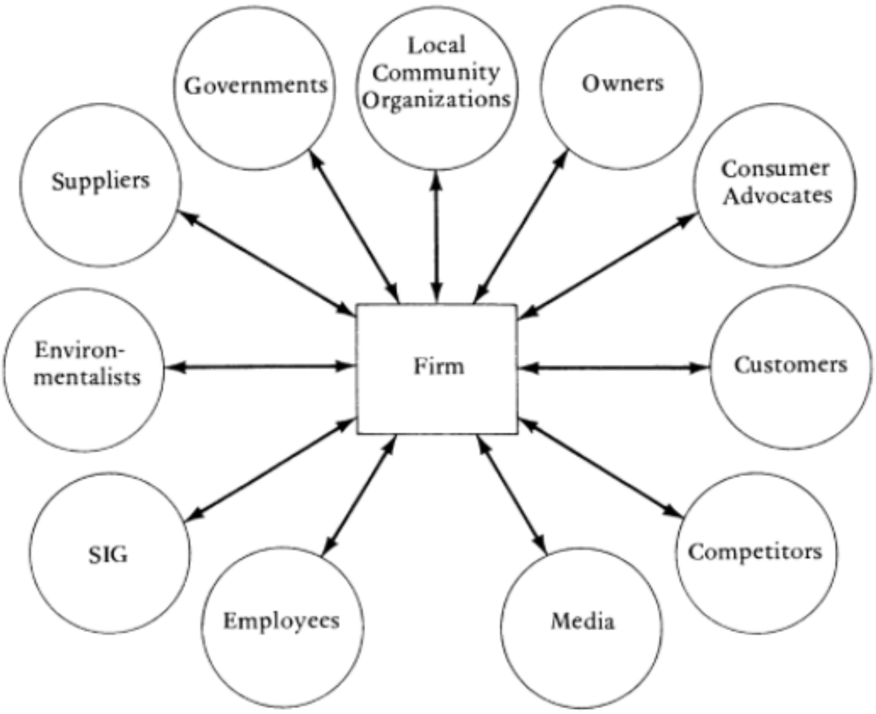


Figure 1: Stakeholder's view of the firm

2.1.2.2 Supply chain manufacturing strategies

Today, the oil and gas industry has multiple different manufacturing strategies based on the parts, lead-time, importance, and materials, as shown in Figure 2 (Arnold 2020, 4). Engineer-to-order (ETO) products require unique designs and customizations. These parts are of high value and the lead time for such parts are long. Typically, components are astored at warehouses close to or at the platforms. Make-to-order (MTO) products are manufactured when an order is made. These parts are more standardized than engineer-to-order (ETO) products, but they also have components of customizations. The lead time on such factors is shorter than on ETO products, but it is still long. These parts are also critical for oil and gas businesses and therefore stored to prevent downtime. Assemble to order are standardized parts without customization that extends the lead time. The last strategy is make-to-stock which are products that gain on the economy of scale. The overall goal is to minimize lead time, have fast on-time delivery, and prevent downtime where the platform doesn't have the parts to continue working, and they lose money because of it (Arnold 2020).

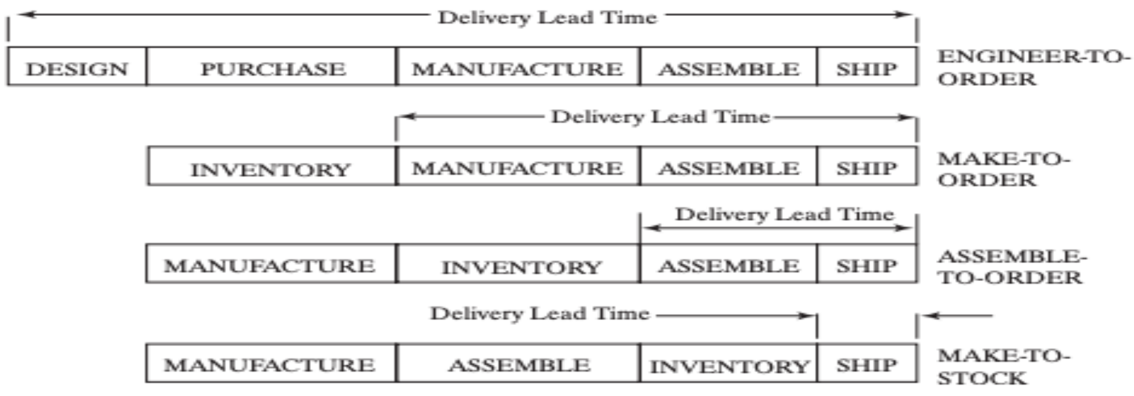


Figure 1.1 **Manufacturing strategy and lead time.**

Figure 2: Manufacturing strategy and lead time

Lean is a broad set of techniques that will reduce and eliminate all types of waste combined. A lean strategy maximizes the value of a product by minimizing waste (Wilson 2010; Sundar, Balaji, and Kumar 2014). The five principles of lean are to specify the matter, identify the value stream, create product flow, let customers pull, and perfection in all links (Thangarajoo and Smith 2015). JIT is a strategy within Lean thinking, and it interprets by Arnold (2020, 430) as the *"elimination of all waste and continuous improvement of productivity."* Characteristic elements of a JIT environment are, among other things, flow manufacturing, process flexibility, quality management, and supplier partnership. In other words, they need to improve the parts without compromising on the price, and all processes that do not bring value to customers should be looked upon and eliminated in some cases (Arnold 2020). Doing changes requires participation from stakeholders early in the process, and this will save them from expensive adjustments later in the process (Arnold 2020)

"The best supply chains aren't just fast and cost-effective. They are also agile and adaptable, ensuring that all their companies' interests stay aligned" (Lee 2004, 1). AM technology could potentially decrease lead-time and increase cost efficiency, but it also needs to ensure agility, adaptability, and alignment qualities to accomplish competitive advantage regarding sustainability. Agility in supply chain management is the ability to make changes based on short-term demand, while adaptability is the capability to adjust supply chain design to meet market changes. Alignment is to establish incentives for partners in a supply chain to improve performance throughout the supply chain constantly. These elements need to incorporate as a part of their strategy to gain a sustainable

competitive advantage and a long-term leading position in the competitive environment (Lee 2004).

2.1.3 SCM in the oil and gas industry

2.1.3.1 Upstream and downstream logistical activities

As seen in Figure 3, upstream logistics represent all activities before production (Aas, Buvik, and Cakic 2008, 286). For the upstream oil and gas industry, the supply chain goes from the original manufacturer to the finished parts reaches the drilling platform. The extended upstream logistics also includes production into upstream activities. Original manufacturer, transportation to base, warehousing, transportation to the platform, and drilling are parts of the upstream logistical activities. Downstream logistics is when the raw oil is on the surface, and the distribution process starts. Downstream logistics includes, among other things, shipping, distribution, selling, and use for different purposes.

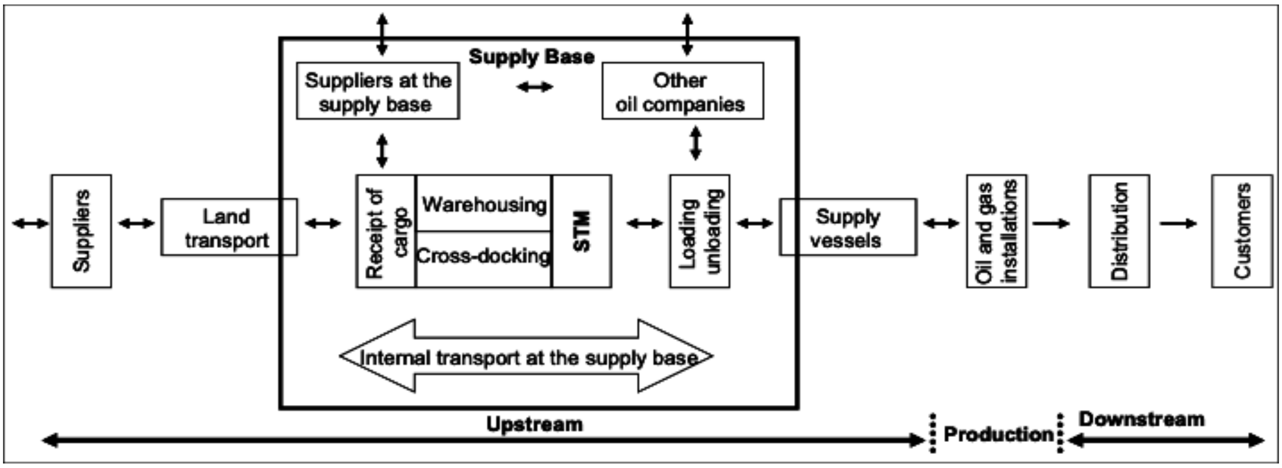


Figure 3: The supply base

2.1.3.2 Centralization vs. decentralization organization structure

The choice of centralized or decentralized production structure depends upon their industry and what they want to achieve. A centralized geographic structure means gathering different processes into one location, for example, gathering all production on oil and gas headquarters into one specific area (Seeds and Khade 2008). A decentralized geographic structure is the opposite of a centralized one, which means that they scatter the processes to different locations domestically or abroad. An example of this could be to use other areas for production or scatter headquarters into smaller places (Seeds and Khade 2008). The centralized and decentralized organization structure is s shown in Figure 4 (Seeds and Khade 2008, 100). In addition to centralized and decentralized, organizations can choose a hybrid model where they take the best from each structure (Seeds and Khade 2008). According to Handscomb, Sharabura, and Woxholth (2016) many oil and gas businesses are reversing a 15-year-old trend, making smaller cores, and using a more decentralized structure.

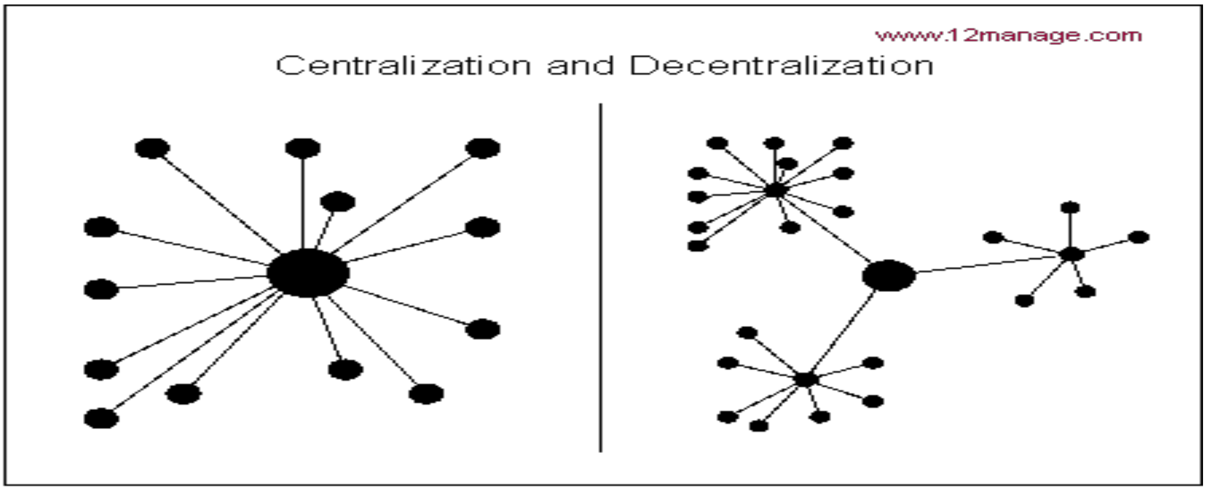


Figure 4: Centralized vs. decentralized organization structure

A centralized structure is a cost-saving structure with a reduction in systems required and the number of administrators. It also simplifies accuracy in reporting, simplifies reporting stronger cooperative values in decision makings, and secures standardization of content, certifications, and competence. However, a centralized structure may lead to more extended responses and changing times due to unexpected changes in the market (Lee 2004). A decentralized structure will increase control at local levels, be more suitable and efficient in training activities, give them the ability to manage more content, and be more reactive to changes in the market. The hybrid model could provide control from a decentralized structure while saving money from the centralized structure. The hybrid model requires them to implement systems that are both centralized and decentralized structure friendly and find places to place the systems with the least amount of disruptions (Seeds and Khade 2008).

2.1.4 Successful supply management

Increased competition due to market globalization, stakeholders' requirements, international regulations, and scarce resources have made leaders of oil and gas firms more aware of supply chain integration and sustainable competitive advantage. This is succeeded by building and maintaining partnerships to gain mutual benefits. The ability to synchronize interdependent processes, integrate information systems, and cope with distributed learning are required to develop and sustain partnerships (Simatupang, Wright, and Sridharan 2002). The importance of relationships and partnerships between different actors in a supply chain to achieve business success has been recognized by, among others, Simatupang, Wright, and Sridharan (2002), Lambert, Emmelhainz, and Gardner (1996), Carr and Pearson (1999) and Sodhi and Son (2009). Findings from the different researchers describe partnership and collaboration as crucial for supply chain efficiency. The collaboration includes intra- and inter-organizational relationships, because SCM involves various organizations and stakeholders. Research by Ryu, So, and Koo (2009) describes the collaboration as an essential part of partnership building and a crucial element in supply chain performance.

As shown in Figure 5**,** collaboration can be slit up into two main categories, vertical and horizontal collaboration (Barratt 2004, 32). Vertical collaboration includes collaboration with suppliers and customers, and it also contains internal collaboration between functions and departments within the firm. The horizontal collaboration is collaboration with competitors or non-competitors business collaboration. Horizontal collaboration could, for example, be sharing manufacturing capacity (Barratt 2004). Many firms have integrated systems for an internal interface, but few of these have achieved complete internal integration (Fawcett and Magnan 2002). This thesis will mainly focus on vertical collaboration, and vertical integration between the upstream part of the supply chain, since oil and gas supply chains are vertically integrated (Carneiro, Ribas, and Hamacher 2010). Vertical collaboration can be performed within a supply chain in many ways, including sharing sales information, joint forecasting, mutual sales targets, and resolving problems related to quality together (Charvet and Cooper 2011). Integrated supply chains are easier to form when firms acknowledge cost benefits and potential competitive power. SC partners collaborating could be established to accomplish mutual goals (Spekman and

Davis 2004). Partnerships with governments are crucial to proceed, and it is one of the keys to success in future investments (Longwell 2002).

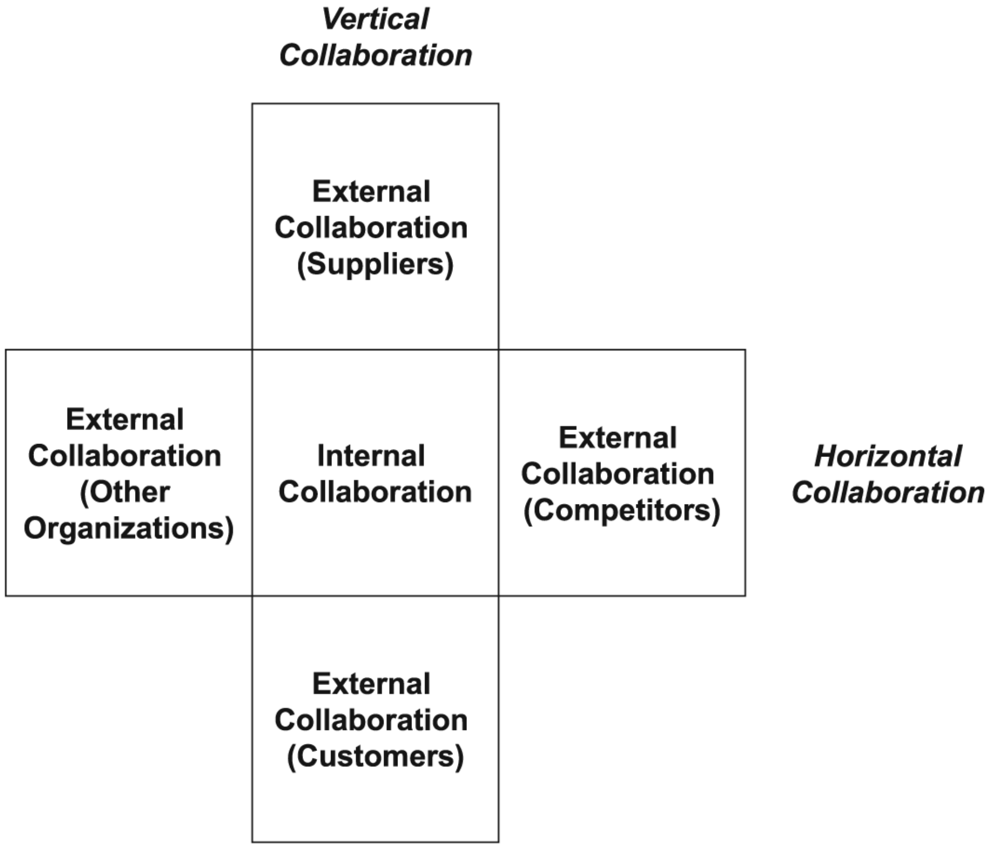


Figure 5: Types of collaboration

2.1.5 Sustainability in supply chain management

2.1.5.1 Definition of sustainability

Environmental focus within management and operations has changed from local optimization to a broader view. This view is where the focus of optimization is on environmental factors, including the entire supply chain from the original manufacturer, to production, customer service, and the disposal at the end of the product lifecycle (Linton, Klassen, and Jayaraman 2007). Rapid urbanization has created social awareness of how the usage of natural resources is being consumed across all industries and is the background of the concept of sustainability (Goh et al. 2020). Sustainability has been increasable discussed in the last couple of years by policymakers, media, journals, and articles from different fields. However, definitions of the phase have raised more questions than answers when discussing sustainability, what should be presented within this field, and what needs to be done today to ensure future generations (Linton, Klassen, and Jayaraman 2007)? One of the most well-known and first definitions of sustainability is generally described as using resources to fill the need of the present without compromising on the requirements for resources for future generations (Rosenberg et al. 1993; Gündling 1990). More modern definitions of sustainability focus more on the world's scarce resources, distributed wealth, and businesses' social responsibilities (Harangozó and Zilahy 2015; Teuteberg and Wittstruck 2010; Mangla, Madaan, and Chan 2013).

All businesses implementing sustainability have in common that they attempt to balance the three aspects of sustainability, economic, environmental, and social considerations and responsibility (Elkington 1998). Nevertheless, the definition of sustainability is still vague because of the number of business goals, concepts, and strategies without much adaptation. There are many definitions and interpretations of the term sustainability focusing on different perspectives. Some reports concentrate on how human activities can be performed without compromising the earth's ecosystem (Geissdoerfer et al. 2017), while others focus less on social aspects, which can be easier for organizations to conduct (Dao, Langella, and Carbo 2011). The oil and gas industry challenges managing natural resources in a deep-water environment, but Cordes et al. (2016) display how conservation tools have proven effects on their environmental management strategies. These tools include, among other things, encompass regulations of the activities by controlling their discharge practices or material used, combined with avoidance rules and having some marine protected areas where they don't operate, and having temporal measures (Cordes et al. 2016).

2.1.5.2 Dimensions of sustainability

The concept of the triple bottom line (TBL) involves the three aspects of environmental, social, and economic issues, and it evolves to support the development of sustainable delivery. These three aspects should be considered balanced and optimized without domination from one or two dimensions. TBL measures the performance of a firm, cooperation, or a supply chain by considering shareholder value, social, human, and environmental capital, all in addition to the original measurement of profitability (Goh et al. 2020). TBL is also referred to as the 3Ps, people, planet, and profits, and it is a part of the changed sight in how we holistically measure sustainable performance (Slaper and Hall

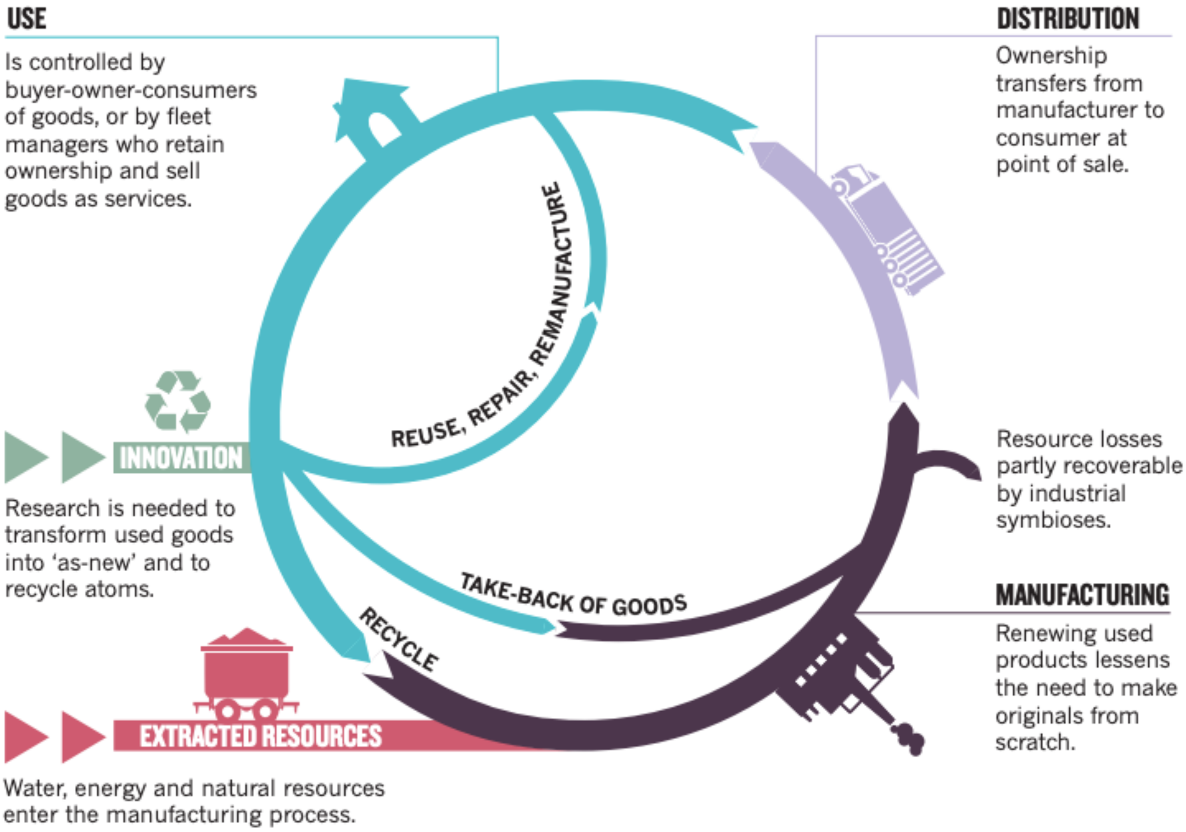
2011). Research performed by Infante et al. (2013) shows that the ranking of these different aspects depends on various criteria. Changing situations and standards lead oil and gas businesses to respond and rank the three aspects of TBL differently (Infante et al. 2013).

The difference between TBL and 3Ps is that TBL has no standardized reporting methods to holistically measure the three dimensions of sustainability (Goh et al. 2020). Even though the three aspects should be considered in a balance, research and literature focus on environmental issues, while social aspects are less mentioned (Ahi, Searcy, and Jaber 2018; Carter and Rogers 2008; Martins and Pato 2019; Seuring and Müller 2008). Faber, Jorna, and Van Engelen (2010) described how the discussion around sustainability was changing from only an environmental view to including organizational and social perspectives. This change in perspective shows that we are moving forward, but we still don't have a total balance between the dimensions. The three dimensions of sustainability appear in Figure 6 (Høvik and Johannesen 2020, 6)**.**

Figure 6: Three dimensions of sustainability

2.1.5.3 Circular economy

Stahel (2016, 435) describes a circular economy as: *"A new relationship with our goods and materials that save resources and energy and create local jobs.*" The idea behind the concept is to reuse, repair, recycle and remanufacture old parts into new to reduce the environmental footprint of the manufacturing process. By doing this, they would use fewer resources than making new parts, throwing away the old ones, and recycling parts at the end of their life cycle. The ideal is that parts, resources, and materials are kept in the production circle for as long as possible before recycling. To have such a supply chain, they need innovations that increase product lifecycle and make the products likely to recycle without losing resources and harming the environment. Using resources as long as possible could potentially cut the nation's emissions by up to 70% and, at the same time, increase the workforce by 4%, and decrease their waste. The circular economy is as shown in Figure 7 (Stahel 2016, 436).



Is controlled by buyer-owner-consumers of goods, or by fleet managers who retain ownership and sell goods as services.

Ownership transfers from manufacturer to consumer at point of sale.

Research is needed to transform used goods into 'as-new' and to recycle atoms.

Resource losses partly recoverable by industrial symbioses.

Renewing used products lessens the need to make originals from scratch.

Water, energy and natural resources enter the manufacturing process.

Figure 7: Circular Economy

2.2 Risk management in the Norwegian oil and gas industry

Risk as a term has been defined by multiple academics and professional disciplines differently over the years. These variations in definitions can be explained by the reflection of different academics and professional disciplines, decision context, and problems being addressed. Sitkin and Pablo (1992, 2) define risks as *"the extent to which there is uncertainty about whether potentially significant and/or disappointing outcomes of decisions will be realized."* This definition of risk in a business includes the three aspects important for understanding it: outcome uncertainty, outcome expectations, and outcome potential. The term risk is used, in many definitions, interchangeably with the term uncertainty (Ritchie and Brindley 2009).

Uncertainty is referred to in many different ways, but their meaning often refers to it as the unpredictability of outcomes (Libby and Fishburn 1977; March and Shapira 1987; Vlek and Stallen 1980). In other words, you do not know what will happen in the future or all details of how a decision will turn out. Uncertainty implies that the outcome can provide opportunities by being positive or cause harm by being negative (Bisson 2014). Kahneman and Tversky (1982) categorized uncertainty into external and internal tension. They discussed how it is essential to recognize the difference when a decision is formed because the different uncertainties require different responses.

- External uncertainty is explained as a situation where decision-makers have no control over the situation.
- Internal uncertainty is when the information is available, but decision-makers don't know about it.

An example is that they can reduce internal uncertainty by searching for information before deciding, and include buffers to handle the situation when external uncertainties occur. External uncertainty can be related to technological uncertainty because they are in a high-velocity market, making it hard to stay relevant and create long-term strategies. Other challenges related to both internal and external uncertainty for oil and gas industries might be increased demand for energy resources, increased competition, the reality and perception of environmental risks, and decreasing global geoscience (Shuen, Feiler, and Teece 2014). The planning phase of an oil and gas supply chain involves uncertainties, as it is difficult to forecast all parameters that need to be considered. These parameters could be related to uncertainty regarding the price of oil and gas, demand and supply (Carneiro, Ribas, and Hamacher 2010)

Risk as a term is mainly seen as a term with negative consequences; the reason is that conclusions consider the harmful effects of a result rather than focusing on how the oil and gas industry can use risks to grow and gain knowledge (Spekman and Davis 2004). Other researchers share the same opinion about risks and define them as an appearance that can potentially impact a situation, organization significantly, or SC negatively (Hopkin 2013; Bisson 2014). In this thesis, I will consider both risks and uncertainties. Researchers and businesses use the term risk to refer to events with potentially damaging consequences. In contrast, uncertainty relates to circumstances where positive and negative effects from the situation are expected and considered. Shuen, Feiler, and Teece (2014) investigate how a dynamic capabilities framework can be used to recognize opportunities and mitigation strategies for risks. These strategies focus on how upstream oil and gas can see the positive effects from risks and uncertainties in the exploration and production phase.

2.2.1 Supply Chain Risk Management in the Norwegian oil and gas industry

There is the various definition of SCRM collected from literature and research. Fan and Stevenson (2018, 205) describe it as follows: *"SCRM aims to develop strategies for the identification, assessment, treatment, and monitoring of risks in supply chains."* While Jüttner (2005, 124) defines SCRM as a *"managerial activity that includes identifying and managing supply chain risks, through a coordinated approach amongst SC members, to reduce SC vulnerability as a whole."* Ho et al. (2015, 5036) criticize how other researchers only focus on parts of or functions of the SC rather than focusing on the whole SC when defining SCRM. They have therefore made their definition that represents a more detailed definition of SCRM: *"an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro-level events or conditions, which might adversely impact any part of a supply chain."*

Although the variations within definitions of SCRM, Rao and Goldsby (2009) identify a shared theme between them, all of them go beyond the ideology of risk management in a single firm. Which means that they focus on risks in the SC rather than risks within only a firm. SCRM is quite similar to organizational risk management. Still, Felea and Albastroiu (2013) argue that SCRM has a higher degree of complexity due to the need for collaboration to cooperate between organizations with individual operations, aims, and views. The theory of SCRM falls between the two theories of supply chain management and risk management, which is described as managing loss and damage in the supply chain management strategy.

Risk management is described by Van Mieghem (2011) as a four-stage process. This process starts by identifying all potential risks. This phase includes macro and micro effects such as demand, manufacturing, supply, information, transportation, and financial impact, as shown in Table 1 (Ho et al. 2015, 5039-5044). After identifying potential risks, we assess the risk levels of all the risks. This phase includes risk analysis and a risk matrix to identify risk levels. Tactical risk decisions will be made in the third phase to determine how to avoid or handle these risks. The last stage in this risk management process is implementing strategic risk mitigation or hedging. The risk management four staged models are stated in Figure 8 (Van Mieghem 2011, 5).

Figure 8: Risk management is an ongoing process with four steps

2.2.1.1 Identify all potential risks or hazards in the oil and gas industry

The first stage is to identify potential risks and hazards. Ho et al. (2015) have gathered different risks mentioned in various articles and research divided into different categories as shown in Table 1 (Ho et al. 2015, 5039-5044**).** First, risks are divided into macro and micro risks, and some researchers use the concepts of internal and external risks. Macros are the unforeseen risks that the supply chain cannot control, while micro risks need to make strategic plans to avoid or use as a positive effect. In addition to these divisions, risks can be divided into three categories organizational risks, supply chain risks, and environmental risks. Within corporate risks, we find the process and control risks, supply chain risks are demand and supply risks. While environmental risks is described in the table as macro risks (Ho et al. 2015). Cigolini and Rossi (2010) divide the oil and gas supply chain into three stages drilling, primary transport, and refining. Therefore, these three stages are differently affected by various operational risks and should be organized with a specifically designed risk management process.

Author	**Macro**	**Micro Demand**	**Micro Manufacturing**	**Micro Supply**	**Micro Information**	**Micro Transportation**	**Micro Financial**
(Chopra and Sodhi 2004)	Natural disaster, war, and terrorism	Inaccurate forecasts, bullwhip effect or information distortion, demand uncertainty	The labor dispute, rate of product obsolescence, inventory holding cost, cost of capacity, capacity flexibility	Poor quality, Dependency on a single source of supply, the capacity, high-capacity utilization at the supply source	Information infrastructure breakdown; system integration or extensive systems networking; E-commerce	Excessive handling due to border crossings or changes in transportation modes	Exchange rate; financial strength of customers
(Gaudenzi and Borghesi 2006)		Customer fragmentation, high level of service required by customers, serious forecasting errors, short lead times	Short lifetime products, linked phases in manufacturing, stock driven supply chain, warehouse, and production disruption	Narrow number of intermediate suppliers, low intermediate suppliers' integration; lack of integration with the final-product supplier;		Lack of outbound effectiveness, transport providers' fragmentation	
(Wu, Blackhurst, and Chidambaram 2006)	Fire accidents; External legal issues; political/economic stability	Sudden shoot-up demand	Production capabilities/capacity; production flexibility; technical/knowledge resources; employee accidents; labor strikes	Supplier management; supplier market strength; continuity of supply; second-tier supplier		On-time delivery; accidents in transportation; maritime pirate attack; remote high-way theft	Cost; financial and insurance issues; loss of contract; low-profit margin; market growth; market size

(Manuj and Mentzer 2008)		Demand variability; forecast errors; competitor moves	Inventory ownership; asset and tools ownership; product quality and safety	Supplier opportunism; inbound product quality; transit time variability		Currency fluctuations, wage rate shifts	
(Wagner and Neshat 2010)		Short products' life cycles; customers' Dependency; low in-house production	Lean inventory; centralized storage of finished products	Small supply base; suppliers' Dependency; single sourcing		Global sourcing network; supply chain complexity	

Table 1: Classification of supply risk factors

Micro-demand factors are often related to uncertainty, inaccuracy, or variability in demand and inventory management. The operational risks are bullwhipped for oil and gas when they go beyond the actual effectiveness and efficiency reduction (Cigolini and Rossi 2010). Many organizations are using safety stocks as a buffer against uncertainty in the oil and gas industry (Van Mieghem 2011). Because of the possibility of having fewer investments in safety stock, analysis shows that JIT inventory is more effective than component substitution (Ho et al. 2015). Manufacturing risks are inventory holding costs, production capability and capacity, inventory ownership, and lean inventory. Supply risks within oil and gas are often discussed, and the risks mentioned are related to poor quality, late delivery, uncertain capacity, and single sourcing. Information factors are related to information delays and infrastructure breakdown in this thesis. Risks from transportation are lack of outbound effectiveness, on-time delivery, and supply chain complexity. The last risk mentioned is financial risk. Exchange rates, costs, loss of contracts, and market growth are significant risks for the oil and gas industry. Longwell (2002) recognizes that long lead times and risks are involved in everything they do within the oil and gas industry.

2.2.1.2 <u>Assess risk level of hazards (Risk analysis)</u>

Figure 9 shows how businesses can categorize potential risks dependent on their potential impact and the probability of occurring (Van Mieghem 2011, 10). The effect is often presented in lost value, income, or increased costs, while probability is measured by frequency of occurrence (Van Mieghem 2011). The likelihood is described by Aven (2015) as high over 50%, medium from 10-50%, and low under 10% probability of occurrence. This model can classify risks into three risk levels: high-risk hazard, medium risk hazard, and low-risk hazard. Risks in the high-risk hazard category are risks in the upper right corner; these are risks that create significant damage, and the probability of it occurring is high. Medium risks are risks with either high probability and low impact, also called recurrency risks, or low likelihood and high impact, also called disruptions. Finally, low-risk hazards can be found in the lower-left quadrate, where both probability and impact are low (Van Mieghem 2011).

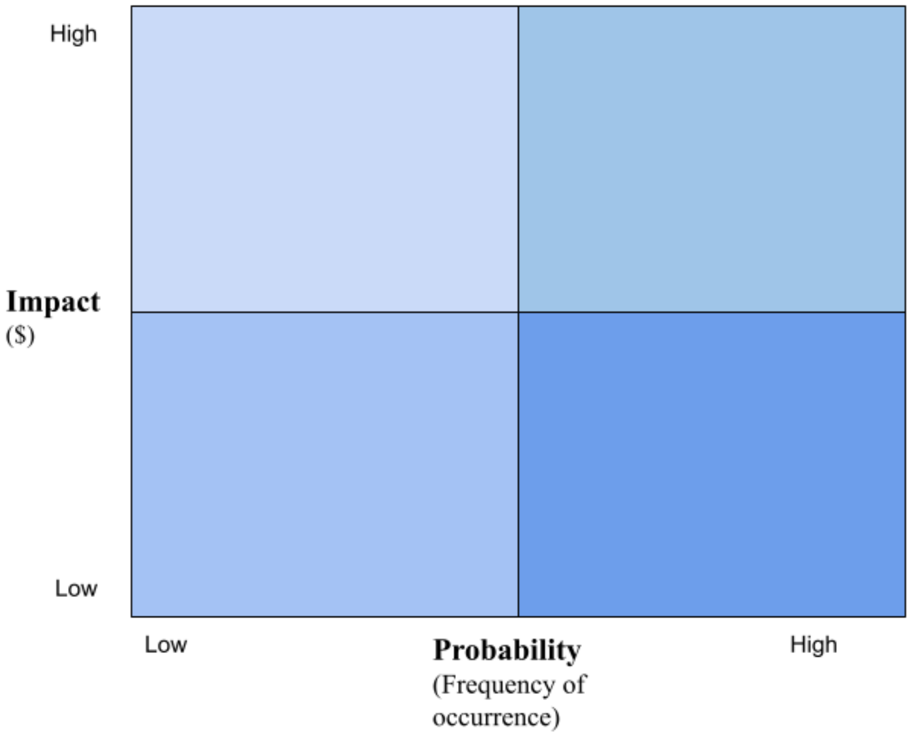


Figure 9: Subjective risk map

This way of dividing risks into different categories and levels can provide a balance between various uncertainties, such as safety and costs. There is a high degree of flexibility in the planning phase, and many alternatives can be considered. Still, they don't have much available information about the different options. Therefore, they are forced to use a relatively coarse analysis method in this phase. As the project starts, they will receive more information and can perform a more detailed analysis. The operational phase available information is extensive, and they can use this to perform a detailed risk analysis.

Later in the process, they have knowledge and experience, but alternative methods are limited. This is the reason it is essential to make thorough risk decisions already in the planning phase (Aven 2015).

2.2.1.3 Making a tactical risk decision

According to Fan and Stevenson (2018) and Aqlan and Lam (2015), the first strategy is *risk acceptance*. This is where they accept that the risk can occur and works around it. This strategy is selected depending on how much risk a firm or SC is willing to take. Typically, this strategy is applied to risks with low probability and low impact on their performance and in a situation where it costs more to mitigate against the risk than the loss from accepting it (Fan and Stevenson 2018; Aqlan and Lam 2015). This acceptance level can be described as risk propensity, which is the willingness to engage in risky behavior and accept uncertainty in the outcome of their performance when making decisions (Park, Min, and Min 2016). Gilley, Walters, and Olson (2002) and Das and Joshi (2007) identified that businesses willing to engage in risky activities also often make more bold decisions and actions that can lead to the development of innovative products or services. In the oil and gas industry, the acceptance level for investments varies according to the willingness of investors to take risks (Carneiro, Ribas, and Hamacher 2010). However, accepting risk is not similar to ignoring it. A risk should still be monitored and tracked to ensure that the consequences of accepting it don't intensify (Aqlan and Lam 2015).

Risk avoidance is the strategy where an SC eliminates all roots to the risk to make the changes small to end up in this risky situation. This strategy is used when both the impact and the probability are high, and they end up in a critical situation if the risk occurs (Aqlan and Lam 2015). *Risk transfer* is the strategy for transferring responsibility to another company (Diabat, Govindan, and Panicker 2012). This strategy is used when the impact is high, but the probability is low, and insurance and contracts are often included within the risk transfer strategy (Aqlan and Lam 2015). *Risk sharing* is like the risk transfer strategy, but they share the risk instead of abdicating all responsibility in this strategy. As risk transfer, risk sharing is chosen when the impact is high but the probability is low (Fan and Stevenson 2018). Finally, a risk mitigation strategy is a strategy where you constantly work to reduce risks to an acceptable level (Fan and Stevenson 2018) and is often used in situations with low impact and high probability (Aqlan and Lam 2015). The goal of monitoring and steering the risk like this is to reduce its likelihood and the potential negative consequences (Norrman and Jansson 2004).

The choice of risk strategy depends on the type of risk and the budget of the firms in the SC (Tummala and Schoenherr 2011). All strategies should be carefully evaluated as risks can be interconnected (Fan and Stevenson 2018). Implementing a response strategy for one chance could affect the SC and aggravate other risks, which means that risk strategies should be considered together. Their risk strategies should be incorporated into the organization’s tactical and strategic planning processes (Aqlan and Lam 2015). In situations with a limited budget, they also need to consider where resources can be most effective and where they need to update outdated strategies (Fan and Stevenson 2018). Risks with the highest potential harmful effects should be focused on (Sarker et al. 2016). For the oil and gas industry in Norway, the risk of downtime of the platform is the highest ranged risk because of the tremendous financial loss if it occurs (Sireesha et al. 2018). This risk will therefore be prioritized when making tactical risk decisions.

2.2.1.4 Implement strategic risk mitigation or hedging

Risk mitigation has not often been addressed in the literature (Ho et al. 2015; Talluri et al. 2013), and the two main risk mitigation strategies mentioned in the research are redundancy and flexibility (Talluri et al. 2013). Increased capacity, redundant suppliers, and increased inventory are redundancy strategies, while increased responsiveness, flexibility, and capabilities are flexible strategies. Taleb, Goldstein, and Spitznagel (2009) explain how lack of redundancy makes organizations unprepared for changing environments; therefore, redundancy could be a good risk management strategy for the oil and gas industry. By analyzing different risk mitigation strategies, Talluri et al. (2013) found that resiliency through flexibility is efficient, while costly redundancy strategies are less effective. Results from this analysis can be used to choose short- or long-term mitigation strategies and prepare for changes in the supply chain for the oil and gas industry. Information gathered can be used by decision-makers to fit their environmental realities to manage their risk without increasing redundancy in the SC (Talluri et al. 2013). Risk mitigation strategies need to be specialized to the individual organization or supply chain since there is no one-size-fits-all strategy (Talluri et al. 2013).

Risk situations need to be constantly monitored to ensure control and the possibility to make changes whenever required before they end up in a critical situation (Fan and Stevenson 2018). Activities related to drilling have been responsible for a higher injury incident rate, and especially injuries related to human factors are relevant (Norazahar et al. 2014). 80% of all drilling incidents are related to human factors, and human errors have been important in controlling and consequence aggravation after an accident (Zhou, Wang, and Zhang 2017). According to Silva (2016) a limited budget explains why the majority of drilling companies have not implemented large proportions of applicable risk control measures. Because of this, it becomes essential to propose specialized methods for this specific industry when it comes to risk assessments, analysis, and control over human factors and risks. Due to its complexity, the oil and gas industry needs to constantly monitor the market and make changes to its strategies dependent on the prices of the oil and imposed sanctions (Lenkova 2018).

2.2.2 Sustainable Risk Management

A sustainable enterprise risk management system (SERM) is system organizations implement to bring sustainable risks into their traditional risk management strategies as an extension. The SERM system will, among other things, include business culture practices, health and safety, environmental management risk, emissions, and governance such as corruption and crime. Research from Cort and Gudernatch (2014) found that oil and gas businesses found it challenging to find common ground when assessing and quantifying sustainable risks against the traditional financial risks they already have in systems. Comparability between sustainable and conventional financial risks is difficult because they cannot be quantified under the same criteria. The timescale of impact is essential to why oil and gas businesses struggle to cooperate risks into one SERM system.

12,5 percent of all risks an organization is facing are related to sustainability. As shown in Figure 9, environmental risks represent 5,4 percent, social and ethical risks represent 5,1 percent, while economic and socio-economic are responsible for two presents of all risks (Spedding and Rose 2007, 7). Benefits from implementing the SERM system could be improved reputation and brand knowledge, more knowledge from talent recruiting, development of new solutions to products and services, and last but not least, reduced risks overall in both organizations and within the SC (Spedding and Rose 2007). For SC managers, identifying sustainable risks, assessing their impact, and developing risk management tools are seen as increasingly critical issues (Hofmann et al. 2014). Table 2 shows how the categories presented in Figure 10 are split into different subcategories (Spedding and Rose 2007, 7). This list shows how harmful these risks are if they are manageable and how much they harm the total value. The most harmful risk is rated as number one, and so on.

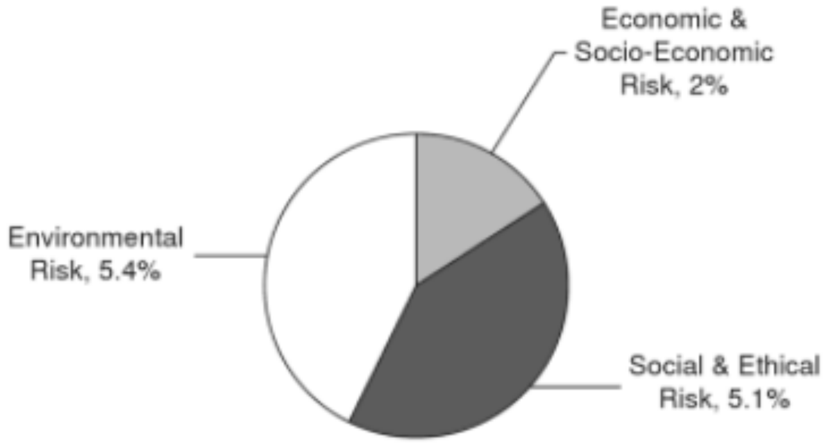
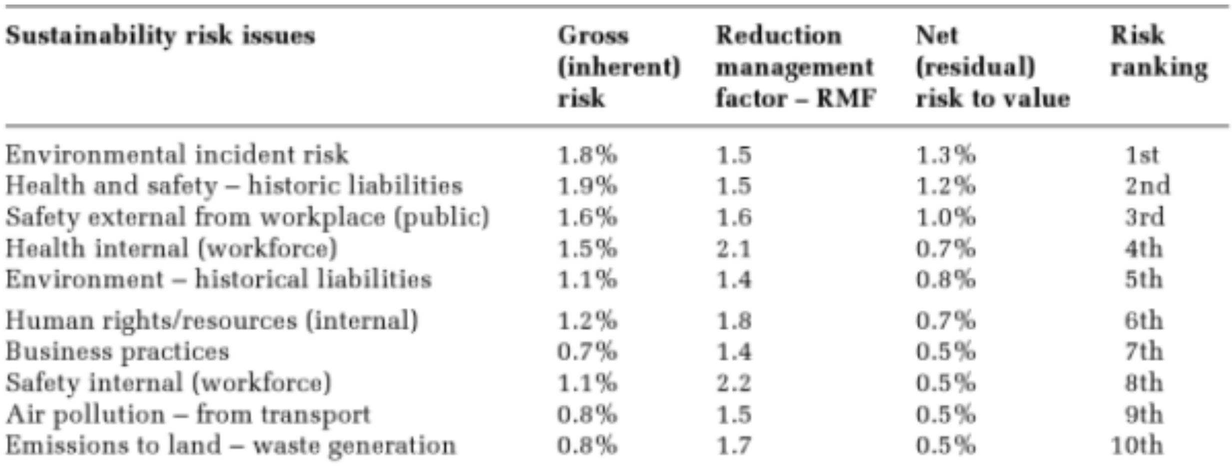


Figure 10: Sustainable risks



Sustainability risk issues	Gross (inherent) risk	Reduction management factor – RMF	Net (residual) risk to value	Risk ranking
Environmental incident risk	1.8%	1.5	1.3%	1st
Health and safety – historic liabilities	1.9%	1.5	1.2%	2nd
Safety external from workplace (public)	1.6%	1.6	1.0%	3rd
Health internal (workforce)	1.5%	2.1	0.7%	4th
Environment – historical liabilities	1.1%	1.4	0.8%	5th
Human rights/resources (internal)	1.2%	1.8	0.7%	6th
Business practices	0.7%	1.4	0.5%	7th
Safety internal (workforce)	1.1%	2.2	0.5%	8th
Air pollution – from transport	0.8%	1.5	0.5%	9th
Emissions to land – waste generation	0.8%	1.7	0.5%	10th

Table 2: Top 10 sustainable risks

3 Context: Norwegian oil and gas industry

This chapter of the master thesis will discuss the research context of the oil and gas industry today and in the AM technology field. I will include the theoretical framework in the context description to better understand oil and gas development and AM technology. This underlaying knowledge will also make it more understandable for readers without the technical expertise within this field. This chapter will begin with a presentation on the oil and gas industry, mainly on the change in supply chain management and performance, dangerous effects on the environment from producing oil and gas, and reasons why sustainability becomes essential. Further, I will describe how climate reports have changed focus areas based on pressure from stakeholders' regulations. Finally, this chapter will explain AM technology, the development in the Norwegian oil and gas industry, and the opportunities and barriers to adopting this type of technology.

3.1 Oil and gas industry in Norway

3.1.1 Historical development

Norway's oil and gas adventure started in 1964 when the Norwegian governance assigned a contract with the American company Phillips to explore what resources the Norwegian continental shelf possessed. Drilling sessions began already in 1966, and it was early in the process established that the Norwegian continental shelf contained hydrocarbons. The first barrels of oil were found in December 1969 in the field called Ekofisk. Further drilling and investigation of Ekofisk in 1970 led to the understanding that this field was a gold mine and that there was possible to find oil longer north than where they now we're settled in the middle of the North Sea (Ryggvik 2015). From the beginning to today, there has been found oil and gas in 115 fields in the Norwegian territory; 94 of them were active fields in 2021. These fields are outspread in the North Sea, The Norwegian Sea, and the Barents Sea (NorskPetroleum 2021a).

Since the beginning, oil and gas production has continuously increased until we met a top in 2004, this does not include 1998 and 1999 when they produced less. In 2004, Norway made 264,2 million saleable standard cubic meters of oil equivalent, as shown in Figure 11 (NorskPetroleum 2021b). From the beginning of the oil and gas adventure, the Norwegian policy was to get international actors to commit fully to keeping Norwegian companies out of the competitive investment market and ensure access to foreign currencies. This was before oil and gas were established in Norwegian territory, and for several reasons, they wanted to prevent Norwegian companies from becoming too involved (Ryggvik 2015).

The most crucial business leader at that time, Fred Olsen from "Norsk Hydro," disagreed with this because of the opportunities and potential in this industry. When the first rig was shipped to Norway, it was hardly damaged in a storm because of bad wheatear conditions on the Norwegian continental shelf. A replacement rig was finalized in Norway the same year, done by Norwegian companies such as Aker Shipyards. This situation was the perfect opportunity for Norwegian companies to watch and learn the techniques to be a part of the oil adventure in their own territory. Norway decided to create a state-owned company to ensure oil and gas resources for Norway instead of giving Norsk Hydro the ability to outcompete and win on recourses Norway possesses. Statoil the state-owned company changed its name in 2018 to Equinor to be representative and a driver of new energy requirements and changed the market situation compared to 50 years ago (Ryggvik 2015; Equinor 2018).

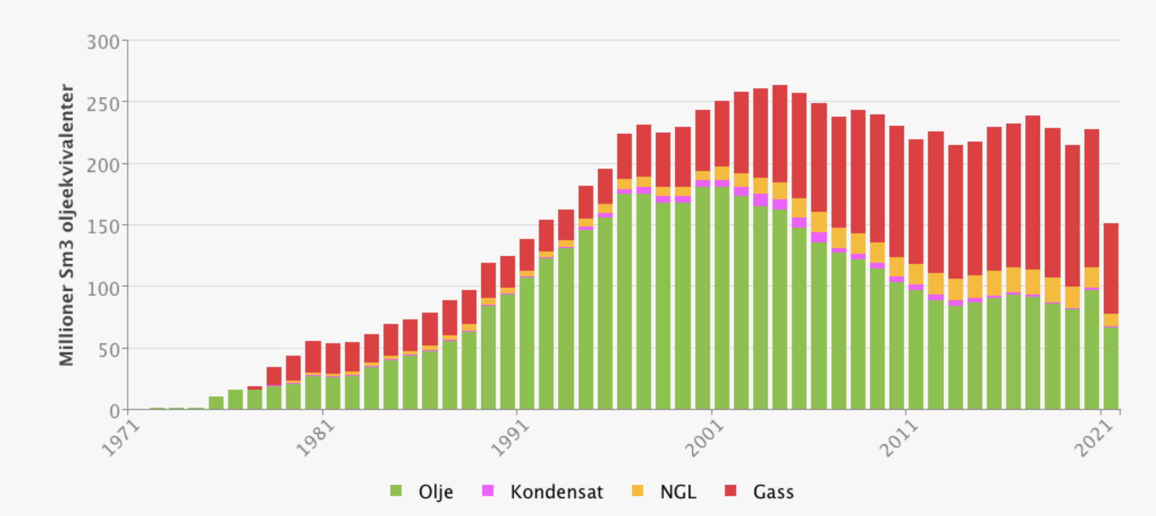


Figure 11: Yearly production of oil on The Norwegian Continental shelf

3.1.2 Oil and gas industry in Norway today

According to SSB.no, oil and gas in Norway employed over 150 000 persons in 2019. Out of these, 68 300 work directly with petroleum, either at platforms or with the construction of oil platforms. Approximately 4 percent out of these 68 300 are not Norwegian citizens and are not residents in Norway. From 2015 to 2017, many employees within this industry lost their job in Norway. The reason is a humongous fall in oil prices and fewer investments because of uncertainty in the market. However, after 2017 this stabilized, and oil and gas are again hiring and employing more people. The maximum number of employees was reached in 2014 when oil and gas employed over 83 000 persons working directly with petroleum. The most significant business with the most influence within oil and gas in Norway today is still Equinor and other companies such as Aker BP, Lundin, Petoro AS, and Wintershall, to mention some (NorskPetroleum).

Norway's welfare society today relies heavily upon the income from oil and gas export to ensure the social welfare society we have built up. This income is significant since oil and gas are responsible for 42% of the total export from Norway each year. The oil price is also directly related to Norway's income from exporting the oil and gas, which resulted in several workers losing their job in the period from 2015 to 2017 (NorskPetroleum 2021a). Revenue from oil and gas is assembled in the Norwegian pension funds. This fund secures management of the money to prevent both today and the next generations, and the Norwegian pension funds had a market value of 11 673 billion NOK in 2021. This money is a part of the Norwegian model, where the administrative government manages oil and gas. The Norwegian model with the funds for commercial activities has inspired other oil nations for years (Thurber, Hults, and Heller 2011).

The oil and gas industry in Norway is, in addition to producing non-renewable energy from oil and gas, producing renewable energy from wind turbines on the Norwegian continental shelf (Mäkitie et al. 2019). The energy consumption on offshore rigs is high and was supplied only by gas turbines positioned on the offshore rig (Korpås et al. 2012). The Norwegian oil and gas industry has been working for several years on how they can supply offshore rigs with renewable energy to replace some of the energy consumption from gas-driven turbines, but only partly (Korpås et al. 2012). Nevertheless, there has been a massive improvement in this field since 2012, and the world first floating wind farm has due in the third quarter of 2022. This wind farm is located 140 kilometers from the Norwegian coast, and it will serve both the fields Gullfaks and Snorre with renewable energy. Implementing this will approximately reduce CO2 emissions by 200 000 tons each year, and this will be a step in Norwegian oil and gas becoming more sustainable (Equinor 2021).

3.2 Effects of regulations on their practices

3.2.1 New regulations

The Norwegian government has, from the beginning, had a significant role in the Norwegian oil and gas adventure. They had the clear ambition to "*develop domestic industry competence that will contribute to national welfare even when oil and gas extraction no longer will induce growth in the economy*" (Heum 2008, 7). Today, taxation is applied to compensate for the environmentally destructive effects of producing oil and gas, mainly through a greenhouse gas taxation called CO2 taxation. This taxation was imposed in 1991 on the flare systems in the North Sea and is identified as a cost on the cost structure of the production. The expected response from businesses is to look for alternative technologies that reduce CO2 emissions and the amount they must pay in taxes. This taxation has resulted in technical improvements resulting in a reduction of flaring and a total gain in the production process and energy efficiency (Celius and Ingeberg 1996).

The tax has changed several times, but it originally started at 0.6 NOK/Sm3 of gas used in energy production and liters of diesel fuel. It changes gradually to suit inflations, and in 1994 it was 0.84 NOK/Sm3. Norway has the highest CO2 tax globally, and this is one of reasons for the development of new technologies and the search for alternative solutions. In 2008, over 20% of total CO2 emission in Norway was caused by the petroleum industry. Although changes are a factum and new technologies have been implemented, there still has been an increased emission level because of increased activity. But by looking at emissions per unit of GDP, we see a significant reduction from 1990 to 1999 due to reduced emissions in the process, changing energy mix, and reducing energy intensity (Bruvoll and Larsen 2004).

3.2.2 External pressure

Additional to pressure from the government, we find pressure from other stakeholders with interest in this industry. International environmental policy, the EU's environmental policy, and other non-governmental organizations (NGO) influence cooperation behavior. NGOs dishonor irresponsible companies, offer professional education, play a role in legislative actions, increase consumer awareness, and engage in environmental projects with businesses, companies, and governments (Harangozó and Zilahy 2015). This influence is shown in stakeholder theory, where the industry is influenced directly and indirectly by other actors in the market (Harangozó and Zilahy 2015). The environmental problems keep increasing in complexity, and this problem cannot be addressed and solved by governments and states alone. Citizens, industries, sectors, and other stakeholders must take a leadership role in finding new solutions and solving problems we face together with the government (Hartman, Hofman, and Stafford 1999).

3.3 Additive manufacturing technology

The development of manufacturing processes has rapidly evolved since the industrial era. An enormous expansion of production, new practices, and new technologies has resulted in continued improvements within manufacturing processes (Gebler, Uiterkamp, and Visser 2014). The progress of AM technology in the last years has created opportunities for businesses to change the organization of activities and improve the flow of materials and goods to benefit from more innovative sustainable solutions (Gebler, Uiterkamp, and Visser 2014). An example of such benefits is where they move their whole supply chain toward a circular economy, shown in Figure 13 under chapter 5.1. Realistically, AM technologies could result in circularity usage of resources and play an essential role in implementing sustainable solutions for a business. When introducing new technologies, it is required to understand better relations between stakeholders and information flows along the material and product lifecycle (Evans et al. 2009).

"*AM and 3DP is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies*" (Mellor, Hao, and Zhang 2014, 194). This technology was developed already in 1986 by Charles Hull in a process known as stereolithography (SLA)(Ngo et al. 2018). The benefits of 3DP technologies are the design, geometrical freedom, and material combination. Using these technologies, they can make customized parts virtually without tools and geometric distances as a barrier. In addition to this, 3DP or AM could cut transportation and manufacturing costs and increase flexibility and productivity in the manufacturing process (Hopkinson, Hague, and Dickens 2006). The digitalization of manufacturing through 3DP plays an essential role in the third industrial revolution (TIR), the age where renewable energy empowers the economy (Rifkin 2011; Berman 2012).

Vichare et al. (2009, 999) explain CNC machinery and technology as "*the combination of machining and supporting activities for a range of multi-purpose machine tools capable of performing subtractive or additive processes in converting raw material into finished products*." CNC technology is an older technology than the 3DP, it is reported as the forerunner for the 3D features (Newman et al. 2008). Peng et al. (2018) describe the main difference between 3DP and CNC technology as the additive or subtractive techniques chosen in the manufacturing process. 3DP is a technology that benefits from its complex structure formations, but it is not possible to sterilize at high temperatures when using this technology. CNC is used in high temperatures, but CNC technology has some limitations. Limitations of the CNC technology is, among other things, related to cutting and routing. Therefore, other technologies are used to complement when this machine reaches its limitations. The CNC machinery process is shown in Figure 12 (Vichare et al. 2009, 999).

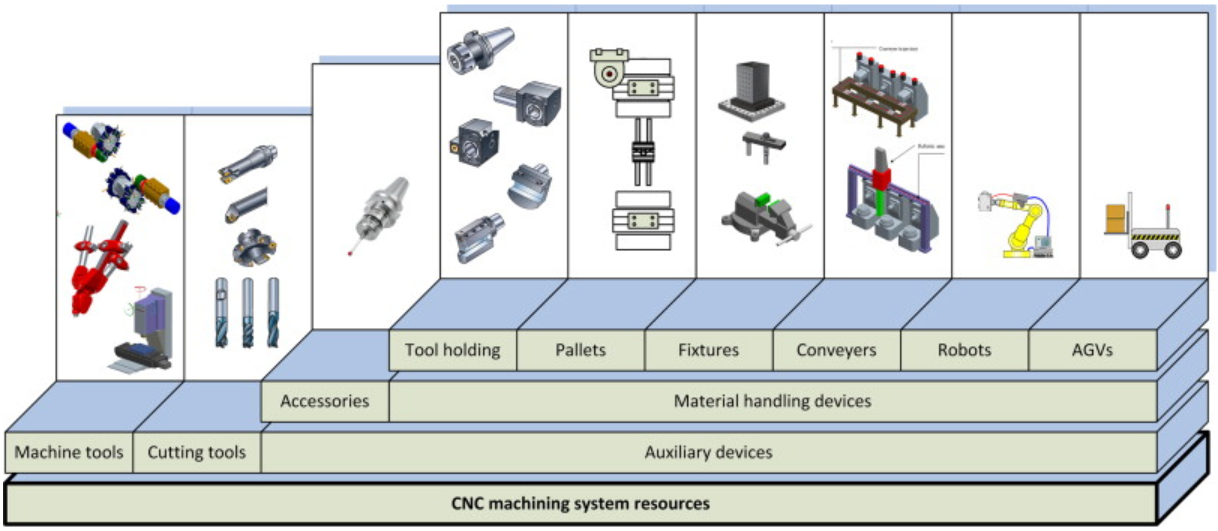


Figure 12: CNC machining system resources

3.3.1 AM technology today in the oil and gas industry

Sireesha et al. (2018) describe AM technologies as the future of oil and gas and manufacturing in general. The development and implementation of AM technology has had a slow start in Norway's oil and gas industry. The technology is now on full speed forward as a Norwegian base company writes contracts with a technical company. These contracts will make the technology company responsible for integrating AM into computer-aided manufacturing (CAM), computer numerical control (CNC), and computer-aided design (CAD). Still, their main task is to create parts in 3D and CNC software and translate them into an STL file. This file will then be divided into thin 2D mathematical equations. Finally, the base company will use these mathematical equations when printing required parts. In this way, the oil and gas industry proceeds with its operations and only includes AM technology in these daily operations and SCM (Sireesha et al. 2018).

Even though the materials possible to 3D print were limited to polymers, metals, ceramics, and their composites in 2018, the technology is continuously moving forward (Sireesha et al. 2018). Oil companies, such as The Norwegian state-owned oil company Equinor, are a part of a tryout project in Brazil. Even though oil and gas have not introduced this technology in Norway, other manufacturing industries have great results from using AM technologies (Ngo et al. 2018; Sireesha et al. 2018). Information and lessons from other sectors can be used directly in oil and gas manufacturing processes. In addition, there are technology firms with knowledge in this field and experience from, for example, the maritime industry, which they can use when implementing it into this industry.

3.3.2 Opportunities and barriers from implementing AM technology in the oil and gas industry

Experiences from AM and 3DP in the aircraft industry show the opportunities for implementing this technology into the Norwegian oil and gas industry. Some materials made with AM technology could be made lighter, such as aluminum parts being 45% lighter without compromising the part's strength. Lighter parts have decreased operating costs, and it even saved airplanes several liters of fuel. Other than physical improvements, AM technology also increased overall supply chain performance. Using JIT production will decrease the need for offshore storage, making manufacturing more cost-efficient and potentially substituting old parts. The design optimization would lead to fewer vendors involved, which will lead to less documentation, less inventory management, and regulatory approvals. Lead time could decrease, and downtime can be averted, which is one of the most cost-saving operations in the oil and gas industry (Sireesha et al. 2018).

AM technologies are a disputed theme, with literature augmenting both for and against its effects. Arguments against it within oil and gas are that AM is perfect for customized low-volume items, but most items used in oil and gas are standardized mass production products. According to Sireesha et al. (2018), 99% of all items needed offshore are products benefitting from economies of scale. Costs of implementing and driving AM technology may decrease as the technology improves and more adopt this technology, but the costs are high today (Johannessen 2019). Renewing old parts to suit AM technology could better utilize the machines, which again forces the price down, and these products can start competing in price. There are some uncertainties regarding licenses from OEMs when making new parts, developing parts, and making parts identical to the original part (Sireesha et al. 2018).

Despeisse et al. (2017) question if 3DP is a way of becoming more sustainable and creating a CE. The uncertainty they describe is whether the material flows become more circular or if there are more negative effects from implementing it. Alternative methods use less eco-efficient localized production, increase the demand for customized goods and increase the output of obsolescence of products leading to higher consumption. These are some of the arguments they are using against AM technology to become more sustainable. Therefore, CE and sustainability should be implemented into the business values and processes before implementing to be a part of a change instead of the whole change (Despeisse et al. 2017). Additionally, Ngo et al. (2018) argued that the limitations of 3DP in 2018 were, among other things, related to the high price of the products, restrictions on the complexity of shapes, materials, and the time it takes to produce one product with this technology.

4 Methodology

"Methodology suggests how inquiries should proceed by indicating what problems are worth investigating, how to frame a problem so it can be explored, how to develop appropriate data generation, and how to make the logical link between the problem, data generated, analysis, and conclusions/inferences drawn" (Jackson, Drummond, and Camara 2007, 23). This part will give an understanding of which methodologies I have chosen to provide an understanding of the situation and answer the research question: *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within the oil and gas industry in Norway***.** Different methods used to get answers to the research questions might affect the outcome of the data collected, resulting in various degrees of the feasibility of the thesis (Vasiliou, Eriotis, and Daskalakis 2009). Because of this, it's essential to choose the proper method for data collection based on your research to get possible results from your outcome.

4.1 Philosophical position

The philosophical position in this master thesis is chosen based on how I perceive the development of knowledge on the selected theme and the research design. Philosophical paradigms are *"conceptions of how we perceive objects and conceive reality"* (Jonassen 1991, 8). According to Jonassen (1991), philosophical paradigms can be divided into two main fields, objectivism and constructivism. Objectivism describes the world as accurate and structured, which can be modeled for the learner. It also has the purpose of "mirroring" reality and its structures (Jonassen 1991). The other paradigm described is constructivism, *"constructivism claims that reality is more in the mind of the knower, that the knower constructs a reality, or at least interprets it, based upon his or her apperceptions"* (Jonassen 1991, 10). Using the objectivism paradigm means finding existing theories, making a hypothesis based on this information, and testing this information to confirm or deny the hypothesis without influencing the findings (Mark N. K. Saunders, Lewis, and Thornhill 2016). This way of finding and searching for information could lead to further development of information in this field that could be proven in another research. The opposite is constructivism which focuses on creating a new and richer understanding and interpretation of social context (Mark N. K. Saunders, Lewis, and Thornhill 2016).

I use social constructivism as my philosophical position in this thesis, because the social reality is affected by my research and the meaning of the research is to provide subjective understanding (Collis and Hussey 2013). By using this philosophical position I aim to seek an understanding of the world from businesses' and individuals' points of view (Creswell and Creswell 2017).

4.2 Qualitative research design

The data collected in this master thesis is obtained using a qualitative research design. Qualitative research design allowed me to get depth information about the subjective assessment of attitudes, opinions, and behavior. Since research outcome is a function of researchers' insight and impression, the results are non-qualitative or in a form that is not subjected to rigorous qualitative analysis (Kothari 2004). Mark N. K. Saunders, Lewis, and Thornhill (2016) argue that my philosophical position of social constructivism is often associated with qualitative research, and quality research is preferable for this thesis. The usage of qualitative research methods was helpful when constructing subjective and social meanings, as well as getting an in-depth understanding of my research question: *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within the oil and gas industry in Norway.* This master thesis builds on both explorative research and descriptive research. The explorative direction of my research helped me understand and reveal how implementing AM technology will affect the Norwegian oil and gas industry. At the same time, the descriptive way allowed me to describe the development of the oil and gas industry in Norway and the continuously evolving demands and requirements in their sector (Steinert 2009; Dulock 1993).

4.3 Case study approach

In this master thesis, I have applied a single case-study approach. I chose Norsea as the focal company for this thesis because they plan to implement AM technology into their routines and tender. They need to change how the entire supply chain acts to be a more attractive option than other base companies competing for the same customers. Inventing more sustainable, cost-effective, and risk-reducing technological solutions is required from multiple different stakeholders. Both Transocean and Norsea are already looking at a solution using digital SC instead of linear supply chains. Still, they have not implemented AM technology as a part of this process yet. This case will look at possible results for the upstream part of the supply chain. In this way, I will get the opportunity to put them up against each other to see if AM technology is a good solution for all links in this new supply chain. The case study approach helped allow, among other things, interventions, critical events, and policy developments to be studied in a real-life context to look at the possible effects of implementing AM into an already existing supply chain (Crowe et al. 2011). Robert K. Yin (2003, 13) defines a case study as:

> *"A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clear. The case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulation fashion, and as another results in benefits from the prior development of theoretical propositions to guide data collection and analysis."*

Using a case study approach produces background material for a relevant discussion about my research question and problems (Gustafsson 2017). The case study approach allows me to do depth research rather than breadth. According to Robert K. Yin (2003), a case study should be considered relevant when we want to answer "why" and "how" questions and when we cannot manipulate the behavior of the stakeholders involved in the study. It is also used when you want to cover contextual conditions and in situations where there are no clear boundaries between the study and the context. Although, as mentioned, I used a single case study as a research design because I wanted to see how AM technology could affect supply chain performance. The information collected in this single case study raised the knowledge I had from the theories and existing public data. The case study helped understanding how theories work in real-time situations and contexts by challenging, confirming, or extending the theory (Robert K Yin 2017). According to Dyer Jr and Wilkins (1991) single case study can produce more and better high-quality theories and is preferred over a multiple case study in some cases. A single-case study is also less time-consuming than multiple case studies, and, as in this thesis, these benefits are preferred (Baxter and Jack 2008; Gustafsson 2017).

4.4 Data collection

Two categories of information can be collected using a qualitative research design, primary- and secondary data collection methods. Kaplan (1964) refers to methods as tools, techniques, or procedures used to generate data, and different methods will be used dependent on available information. Primary data are real-time information gathered through interviews, observations, and focus groups. In contrast, secondary data is already existing data material collected by other researchers for the same or different purposes (Hox and Boeije 2005). This master thesis will be based on primary and secondary data methods to get a broader and broader understanding of the phenomenon.

4.4.1 Primary data

According to Hox and Boeije (2005, 593), primary data is *"data that are collected for the specific research problem at hand, using procedures that fit the research problem best."* There are multiple different ways of collecting primary data, but this thesis will mainly focus on in-depth interviews as a source of data collection.

4.4.1.1 Interviews

In this master thesis, I will conduct four in-depth interviews with key representatives from different businesses in the upstream supply chain and businesses involved in this transition phase. Interview objects include Norsea base firm as the focal firm, technical and logistical department in the drilling company Transocean and Wilhelmsen as a third-party provider of this 3D printer service. Most of these interviews were conducted via teams meeting from January 15th to January 31st and recorded to make the transcription phase easier and more accurate. One of the interviews was conducted by telephone at the middle of April. Recording requires written agreements with contestants, which will be performed to ensure the validity of the collected data. The interviewees are people in different firms working with AM projects, heads of logistics, technology, or managing specific parts in the manufacturing business. The interviews will be in Norwegian and translated into English before presenting them in the master thesis. In addition to interviews, communication regarding technical questions and questions, in general, will be discussed by email and meetings.

Semi-structured in-depth interviews are the data collecting method chosen. This type of interview allows me to provide more detailed information without deciding which answers I get. This will give me more personal responses, and the questions asked will be adjusted according to their answers or if something is unclear and needs more clarification (Mark N. K. Saunders, Lewis, and Thornhill 2016). Additionally, since the philosophical position I chose was based on social constructivism, I will get a clearer understanding of the interpretation the interviewers have of the phenomenon I study (Mark N. K. Saunders, Lewis, and Thornhill 2016).

The vital communication with the different interview participants from firms will help me have follow-up interviews if needed and an open dialog over email. These follow-up interviews and dialogues will provide this thesis with in-depth data. The firms will not get a chance to see what I have written before the findings are out. The findings will be sent to them to approve the statements they have provided to ensure ethics and the correct fabrication of the interviewers. Writing questions, holding interviews, and writing transcriptions in Norwegian will be critical for data collection. The reason for this is that it is easier to express yourself and understand in your native language, which will prevent miscommunication and misunderstandings.

4.4.1.2 Triangulation

The concept of triangulation refers to looking at a research problem from more than one different points of view (Flick 2004). Which includes using two or several methods for data consumption and collection, such as interviews, document analysis, and observations (Creswell and Creswell 2017**.** This master thesis contains different data sources, and I can therefore ensure triangulation of the presented data. When using a case study, triangulation helps to strengthen the construct validity of my case study (Robert K Yin 2017). Using a triangulation strategy with multiple data sources opens for a broader description of the phenomenon, because it helps me look at the different perspectives from the various sources (Robert K Yin 2017). According to Collis and Hussey (2013), distinct impressions of the phenomenon give a more detailed picture of the actual case situation.

4.4.2 Secondary data

Vartanian (2010, 3) defines secondary data as *"secondary data can include any data that are examined to answer a research question other than the question(s) for which the data were initially collected."* Secondary data can also be understood as *"information that already exists in the form of publications or other electronic media, which is collected by the researchers"* (Easterby-Smith, Thorpe, and Jackson 2012, 12). Predominantly, the secondary data used in this master thesis mainly builds on scientific articles and journals gathered through ScienceDirect and Google Scholar by searching for specific topics related to methodology, supply chain management, risk management, sustainability, etc.

Further on, the secondary source of empirical data was used to collect information about the oil and gas industry, the development of AM technologies, new rules and regulations. In addition to press releases, Norwegian regulatory norms and acts, and annual reports from both the focal firm, oil drilling rigs and official websites. The work with this master thesis started as a backward snowballing technique where I began sourcing relevant papers before building questions to collect primary data (Danglot et al. 2019). The secondary data was a perfect supplement to our preliminary data, and the primary data collected was built upon the obtained secondary data. This method allowed me to show a more comprehensive understanding when using historical data and real-time information from the participants working within the oil and gas industry today.

4.5 Data analysis

The result I had from using semi-structured in-depth interviews as my method for collecting data was text material with a lot of information and depth in context descriptions (Blee and Taylor 2002). By choosing a semi-structured interview guide, I will have to carefully select a form of analysis that makes it easy to collect and simplify findings (M.N.K. Saunders, Lewis, and Thornhill 2015). Therefore, the data analysis and transcription phase were crucial in finding the correct elements of the interviews and rewriting them in the proper context. In addition, the transcribed data from interviews were marked with different colors throughout this phase to sample and organize all data. Color coding was essential because of multiple sources' additional information obtained in interviews.

The coding mechanism was then used to rationalize and analyze essential words, phrases, sentences, or paragraphs from the interviews, already marked out in colors, so the information generated generates reports (Atkinson 2002). The coloring, defining the different categories, and coding process was time-consuming, but I perceived this time timesaving long-term. Then a thematic approach was used when analyzing the data. According to Castleberry and Nolen (2018), the thematic analysis identifies, analyzes, and reports themes and is often included across all qualitative design studies. Braun and Clarke (2012) describe thematic analysis as an accessible and flexible method for analyzing diverse and complex data, such as data from qualitative data analysis. The most important subjects from the interviews were connected to find meaningful categories that showed the main features of the interviews. The collected and analyzed data were then linked to the theories about supply chain management and risk management to get general information that was included to answer the research question; *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within the oil and gas industry in Norway.*

4.6 Quality of research

Quality of research is essential to find trustworthy sources with information that are both real and crucial to answer my research question (Glasziou, Vandenbroucke, and Chalmers 2004). By using reliability and validity, I ensure that the information provided is trustworthy and relevant to the context of my research. These two criteria will also be a guideline to show how I worked and solved issues, and a generalization of this master thesis is expressed in the end.

4.6.1 Reliability

Kirk, Miller, and Miller (1986) identify the three reliability types mentioned in qualitative research; the degree a measurement reputedly remains the same, the stability the measures have over time, and the similarity of results in similar measurements performed in the same period. In my case, where I use the case-study approach, there are two keys to reliability, case study protocol and the development of a database. The first stage is the protocol, where an interview guide is designed. Then there is the case study database, where I keep a copy of the interview guides, recordings, transcription, and all secondary data collected (Ellram 1996). In addition to primary data collection, secondary data was also crucial in increasing the reliability of my research. By looking at the three types of reliability, secondary data and public data, we see that they all focus on stability over time, which means that this information will increase the reliability of the research.

I facilitated research with a high degree of reliability. Ensuring reliability was done by giving the participants the ability to read the interview guide days before the interview. To ensure reliability, I sent them the findings part of this thesis, in order for them to verify or potentially correct where misunderstandings occurred through the discussion. As a result, misunderstandings were avoided, and the communication opened for a positive debate. As an interviewer, I tried neutral positioning and avoided expressing personal opinions. Own expressions could have changed the result of the collected information and possible undesirable directions that did not answer my research question. How the different interviews were interpreted, transcribed, and understood provides guidelines for the outcome. My own opinions, misunderstandings, or wrong information could potentially be destructive to the result of my case-study research.

4.6.2 Validity

According to Easterby-Smith, Thorpe, and Jackson (2015, 343) validity is "*the extent to which measures and research findings accurately represent the things they are supposed to be describing.*" Therefore, constructing a detailed research design and data collection method was crucial in my research to ensure validity throughout the research process. In addition to these measures, I triangulated the data collection. This process showed that it was accurate according to the choice I made through the process. All these measures added validity to the study (Creswell and Creswell 2017).

4.6.2.1 External validity

"*To generalize is to claim that what is the case in one place or time will be so elsewhere or in another time*" (Payne and Williams 2005, 296). According to Gomm, Hammersley, and Foster (2000) survey research is more generalizable than using the case study method used in this research. Case study research has been criticized for the findings not being generalizable. Therefore, Stake (1978) said that knowledge is a form of generalization, and using a naturalistic generalization instead of scientific generalization is more suited when using a case study approach. According to Stake (1978, 6) naturalistic generalization arrives "*by recognizing the similarities of objects and issues in and out of context and sensing the natural covariations of happenings."* In addition to the naturalistic generalization, Robert K. Yin (2018) divides the generalization of the results from a case study into two categories; statistical and analytical generalization. Statistical generalizations build upon research from surveys, and the conclusion is about a population based on empirical data. Analytical generalization is the most used in case study research and is also interpreted in this master thesis. Analytical generalization is based on the case study, and the data collected goes beyond the case's surroundings. The theoretical prepositions from the case study form the base for my analytical generalization (Robert K. Yin 2018). I ensured analytical generalization by using previous research on AM technology in this industry and compared it to the findings in these interviews.

Flyvbjerg (2006) recognizes that one cannot generalize from a case study, and he has presented some attempted solutions to solve generalization. This thesis builds upon knowledge from risk management and supply chain management. Making my research on context-dependent knowledge instead of predictive theories is more valuable, according to Flyvbjerg (2006). Furthermore, research done in this thesis can be supplementary or contribute to the development of other methods and can therefore be generalized based on the case study (Flyvbjerg 2006). Biased data is a trap that I was aware of throughout the whole research, but according to Flyvbjerg (2006), bias might happen when using other methods. Presenting the historical development of AM technology and new research on this field made it easier to analyze, conclude and make the collected data generable.

4.7 Research

Research ethics have been introduced by Mark N. K. Saunders, Lewis, and Thornhill (2016, 264) as *"standards of behavior that guide your conduct concerning the rights of those who become subject of your work, or affected by it."* Most countries in Europe, especially in the western world, is subject to ethical regulations and are reviewed by a recognized ethic committee (Wiles 2012). In addition to the legal rules mentioned, Wiles (2012) includes the individual moral framework, ethical framework, and ethical regulations such as professional guidelines and disciplinary norms as factors in shaping how decisions regarding ethics are made. Through my research and investigation of this theme, I will recognize and encounter some ethical concerns that need to be considered. These ethical concerns could appear in all stages of the study (Oliver 2010). With ethical considerations and reflections in the back of my head, I started by being honest and open with all participants of this research about my research, their rights as participants, and the thematic and sent them an informed consent (Creswell and Creswell 2017). Being open and honest through the process also made me obtain what Mark N. K. Saunders, Lewis, and Thornhill (2016) call traditional access.

In addition to the mentioned regulations, Molde University College also has rules that all research written for them needs to follow plagiarism, falsifying, authorship, evidence, data, findings, and conclusion. These rules from Molde University College are similar to other theories such as Creswell and Creswell (2017). Before starting data collection, I also needed to get my research and research methods approved by Norwegian Center for Research Data (NSD). This approval ensured that I followed all ethical regulations and rules to ensure no harm to any participants. In this formal application, I had to explain and justify how and why I was collecting data and a description of how I stored data from interviews safely.

Furthermore, all personal data from interviews were placed in secure files on my computer. Accessing these files was only possible from my laptop with a password only I knew. Based on all actions made to secure ethics in research, I feel safe that my study builds on good ethical standards throughout the whole research process.

5 Case description

This chapter will explain the case and clarifications related to this case by presenting how they want their future supply chain to look and management of this supply chain. In addition, the technology they want to implement into their daily operations is mentioned as a part of their new digital supply chain or network. Stahel (2013) describes why businesses attend this transaction into digital systems: "*Businesses can ignore this transition these shift for a long time, but when others have success with it you will no longer be able to compete with them.*" The focal company, in this case, is an oil and gas base company in Norway serving several offshore platforms with equipment. They plan to deliver more renewable solutions and want to be a market leader within AM technology in this industry. All these elements are essential to understanding the settlement of my research problem: *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within the oil and gas industry in Norway.*

5.1 Digital network supply chain

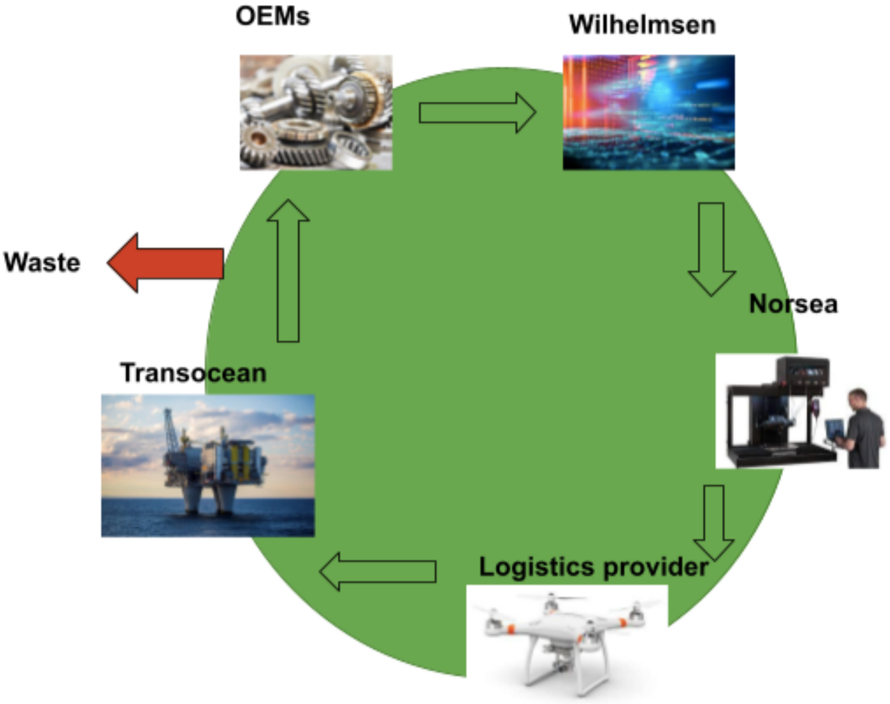


Figure 13: Digital supply chain

Figure 13 is a drawing made to illustrate what the oil and gas industry wants the supply chain to look like in the future. This figure is called a digital supply chain or digital network since there is a connection between all links in the supply chain and is circular to reduce waste and save resources (Stahel 2016). In this process, some waste will still be released because they are not using 100% renewable resources, and the technology is not capable of reusing or recycling all materials used today. However, this will, including the lack of resources used and the technology available, still be more sustainable than what they are using today. As shown in the figure, the OEMs are still a part of the supply chain. OEMs own the rights of the goods produced and still produce parts gaining from the economy of scale. Today, approximately 10% of all components used by drilling companies out on platforms are possible or profitable to produce using AM technology.

The certifier in this upstream supply chain is the Wilhelmsen group. They are responsible for building up the files they use for the AM technology and working together with OEM to ensure rights and certificates. Norsea Group will increase its processes in this new digital network by being responsible for the printing process, but this requires that the technology is installed on its base. They plan to build and install an i4 factory on their base that includes 3DP and CNC technology to produce parts close to the platforms—making Norsea react quickly and be a leader part of the new green economy in the industry. Other industries and businesses can gain from Norsea implementing AM technology on base, which will be a win-win situation. This way of thinking is a JIT way of producing; they produce after demand instead of keeping most items in a warehouse.

Logistics providers could, in some cases, use drones as a mode of transport where time is critical. Drones are a more developed technology than 3DP, and this technology can be used for specific transportation instead of helicopters shipping almost empty vessels out in the sea. This technology is also developing, and there are considerable opportunities in the future. Transocean as the operator, will be affected by this change. The question is, in which way will they be affected and how much? They have already seen results from other technological investments such as wind turbines. These wind turbines supply the platform with renewable energy to reduce fossil fuel in their production process. There are therefore a believe that also this investment will be a part of keeping them competitive and sustainable. As seen, AM is only part of a solution to their problems and goals, they will include this into current and future technologies to achieve their goals.

Figure 14 illustrates what this new AM technology process can look like in this supply chain (cnclathing 2021; Sinoworldindustrial 2022; AMT 2022). First, it starts with the designing phase, where Wilhelmsen designs the parts together with both Transocean and OEMs. Feature clarifications are essential in this phase to make parts that fit perfectly to the requirements. Wilhelmsen will also be responsible for uploading the file into the digital warehouse and will constantly work to develop the technology to expand this digital storage. Finally, Norsea will be responsible for the printing process, which means that they will choose the wanted material for each part and print it in the i4 factory located at their bases. Finished parts will then be shipped out to the platform organized by Norsea. Transportation offshore can either be performed by vessels for less critical items, by helicopter, or mostly drone technology in the future.

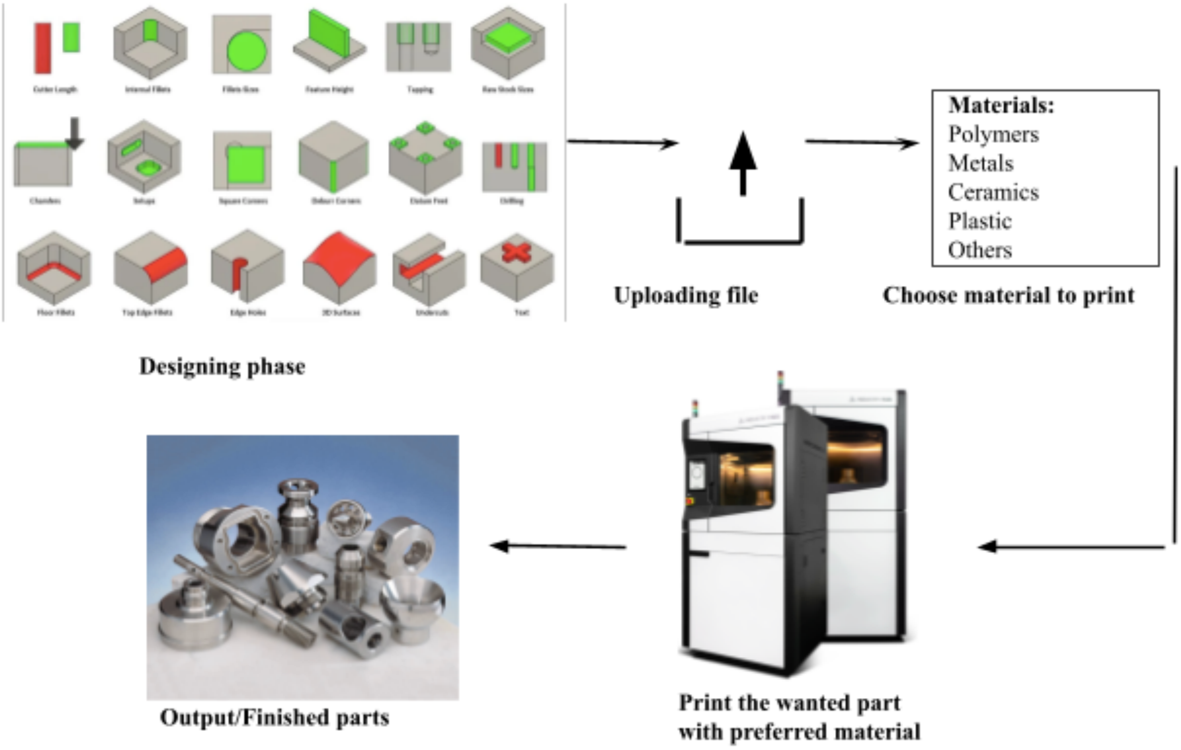


Figure 14: Process of printing oil and gas parts

There are different 3D printers specialized for different types of work, and in Figure 14, we see an Industry F421 3D printer. This printer is equipped with actively heated chambers that allow them to choose high-performance materials. This machine has a high printing speed and is one of the fastest solutions for engineering-grade materials. The printing speed of such a device is up to 400 mm per second. The chamber volume is

380x380x420 mm, which allows them to print bigger parts. There is a wide range of materials possible to print in this machine, including high-performance thermoplastics and composites, and more used materials such as polymers and metals. In addition to this, the Industrial F421 machine can include hardware that allows Norsea to print using reinforced materials. Using other materials can improve the production of the most heavily loaded construction parts (3Dgence 2022).

They could potentially use PEEK, PEKK, or ULTEM materials to replace the old materials used. These are materials with high-performance polymers that could substitute metal parts (3Dgence 2022). An alternative to the F421 could also be the DMP Flex 350 or the DMP Flex 350 Dual 3DP for metal parts. These machines have high precision and can easily switch from one operation to another. In addition, it includes integrated software and can, therefore, easily be attached and work together with other technology. They both provide high repeatability and quality, and this 3DP has already printed over 500 thousand complicated metal parts, so the technology has proven results (3dsystems 2022). The DMP Flex 350 and the DMP Flex 350 Dual can be seen in Figure 15 (3dsystems 2022).

Figure 15: DMP Flex 350 and DMP Flex 350 Dual

5.1.1 i4 factory

I4 factories is an automatic machining factory in an early phase. This factory delivers effective and eco-friendly solutions by being standardized, fully automized, and close to the user of the parts. Positive aspects of this i4 factory are shorter lead times, lower total costs of production, less administration work, and better availability and documentation. In addition to these benefits, it is also a way of producing sustainability with less waste, travel, transport, stock levels, and personal injuries. The first factory is already installed at Rubbestasneset quay, but this factory only uses machinery and not AM technologies. A pilot production unit for satellite factories placed locally at customers has begun, and the future i4 factories include AM technology such as CNC and 3DP as integrated services in these factories. The work of incorporating AM technology into these factories has already started and will be a practice within a short time in the maritime industry (sunn-tech). An i4 factory is as shown in Figure 16 (sunn-tech).

Figure 16: i4 factory

6 Analysis

6.1 Responsibility and processes when critical parts break down today

Transocean will be the first to recognize when critical parts are defective, and they will start the process of finding nearby storage with this component. If this is the situation, they will contact the storage facility and arrange shipment of this part immediately. Suppose this is not the case and they do not have this part stored anywhere. To prevent downtime, they contact the manufacturer directly to order them with fast delivery, including for example helicopters. Downtime for Transocean means that they cannot rent out the platform and lose millions on lost profit, and therefore have parts at a total cost of 10 million dollars stored on one platform. For some unique occasions, they do not have the part they need on any storage, either on other platforms or at the warehouse on the base. In advance of critical components breaking down, the technical department in Transocean has plans and solutions to these problems. This department is responsible for planning, by using short-term, mid-term, and long-term planning based on how critical these parts are, their lead time, and the probability of breakdown.

Critical components are stored initially at the platform as a part of the mid-term or long-term planning done by the technical department in Transocean. This planning goes from 1,5 to five years ahead to prevent unsure situations where they end up in critical situations. Orders within these categories are manually placed, while orders within the short-term planning horizon will have an automatic order placement when inventory goes under a given number. A situation when critical parts break down and don't have them stored closely, can be shown in Figure 17. Transocean starts to contact a manufacturer with a requisition, and the process continues with the manufacturer reaching the subcontractors to get each component of the final part. This linear supply chain requires many links to be synchronized to make the final product. This ordering process is a time-consuming and expensive way of getting the right parts, and this does not satisfy the need for shorter lead times to prevent downtime at the offshore platforms.

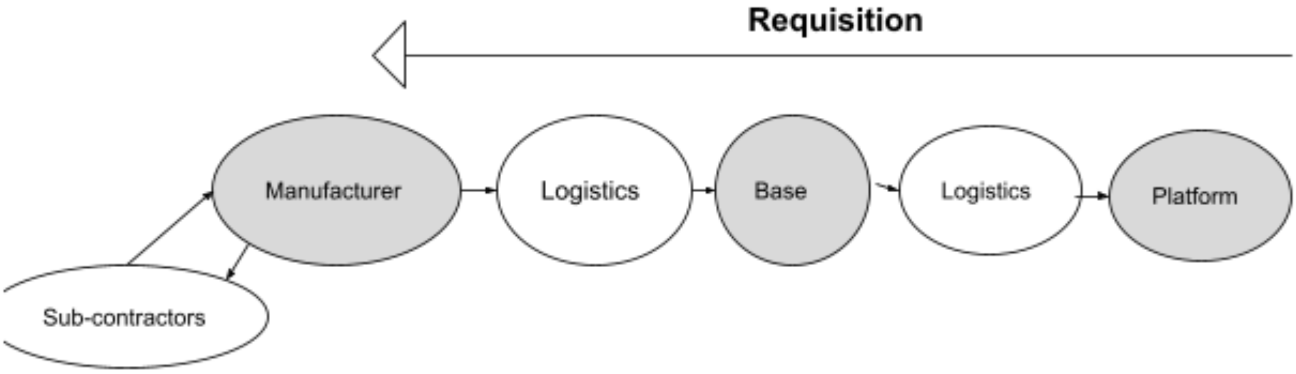


Figure 17: Supply chain for critical parts

Norsea is the logistic operator in the supply chain, which means they are responsible for the last-mile delivery to the offshore installation. They have operators owning and drifting storage at their platform, which can be evaluated as valuable to their customers. When critical parts break down, they will, in some cases, have the component in the storage on the base, or they get it directly from the manufacturer. The final component from the manufacturer always includes a marking, which describes where to store it or shipped directly to the platform. They will order helicopters and arrange logistics from the base and Sola airport for critical parts or send them by supply vessels in cases where the risks of downtime are lower. In the future, drones will also be a more practical mode of last-mile delivery. These drones can be ordered as a “taxi-solution” rather than the fixed transport schedules. Overall, Norsea has no direct impact on the decision-making for now. However, their warehouse includes 404 000 parts, some of them stored for years and multiple resources are required yearly just to count and drift the inventory. Therefore, reduced inventory at different locations could be an essential element in the total cost savings of implementing AM technology.

Wilhelmsen will have the most responsibility in the planning process of implementing AM technologies into this industry. They will be responsible for engineering, printing, testing, certifications, and guiding Norsea through implementation. In addition, the portfolio of digital parts from other industries and parts made especially for this industry need to be put together into one digital platform. Their responsibilities also include close communication with spare part manufacturers, OEM and the market, and control over agreements, regulations, and technical specifications. Therefore, the digital platform is its primary service and they categorize itself as an end-to-end digital production partner. The initial plan is to print critical parts and build up digital storage on these items. Then they will consider other components in a five to ten years perspective when the technology has developed, and prices have decreased because of this development.

Whether the i4 factory should be located on Norsea's bases or at other locations has not yet been decided, but there are arguments supporting both alternatives. Wilhelmsen raised that the i4 factory could be placed at Norsea bases and locations only if they become a production partner and gives opportunities for organizations in other industries near the base. Choosing to locate the factory on the Norsea base requires the needed facilities and area to house the factory. Norsea describes it as advantageous to locate the i4 factory at their bases because of the optimized lead times for their customers, and opportunities to supplement this factory with other ongoing technical projects, such as drone technology and remanufacture machines. Together, multiple technologies will be advantageous for shorter lead times for their customers. In addition, they argue that their eco structure is favorable with 10 000 supply vessels entering their three bases yearly, there are also other businesses nearby the base that could get advantages from this technology. With this location, Norsea would have used drone technology for the last mile delivery of critical elements to shorten lead-time and sustainable footprint without including more on-land logistics. In addition to Norsea's argument for on-base factories, there have been reported optimization projects clarifying the profitability of having these technologies on land.

6.2 The SCM and parts after implementing AM-technology

Transocean will work the same way as before, but instead of contacting the OEM directly for parts, they will contact Wilhelmsen. Wilhelmsen will be responsible for sending the orders to nearest factory location or design them into the digital storage before sending the order. This implementation will lead to stronger cooperation and relations internally and between the different parts of this SC. Wilhelmsen have approximately 40 partners and some of them are OEMs in the oil and gas industry, which have to be included in this process. The technical and supply chain departments, both from Transocean, will work closely internally to decide technical descriptions and lead times and externally with Wilhelmsen in the planning phase. Further in the process, Transocean will work the same way as before, but with less long-term planning and storage.

Norsea sees itself as a more significant support to its supply chains after AM is implemented. They will have a more substantial role than the original operation position when printing the components on demand from the digital database, and managing the logistics to the different customers on land and offshore. They will be responsible for the new i4 factory located on their base, including AM-technology such as 3DP and CNC, and other technologies. This factory will include machines that remanufacture old parts into raw materials, and these raw materials can be used in the production of new parts. They will focus on positioning in the market to gain a win-win situation with other actors, with focus on the values of this supply chain. More vital communication and relationship building is required when Norsea takes a more significant role in managing this supply chain. This role will prepare them for new work requirements in the next few years and changes in the needed labor. The ones that count the storage for Norsea will, as technology improves, most likely have another role in the business in the future. These changes might lead to future opportunities, value creation, and new areas of interest. Today, the SC uses virtual inventory to map which location parts are stored and plan to ship between the locations. Digital storage could be incorporated as a further development in this system. Instead of only showing where the pieces are in stock, it could be an order base to decrease storage at different offshore locations. Systems like this make it easier to order parts, and they no longer need the exact sharing mechanisms across platforms as before.

When it comes to what materials that can be printed and are profitable to print, all interviewers believe that they are only in the starting phase. Wilhelmsen assumes that the 4% possible to print in 2018 will likely be 10% in 2022, and it will increase as the technology improves. Realistically, this number will increase more each year as parts and technology improve and more industries adopt this technology. They have seen the enormous progress within the technology used in drones and see the same potential within the AM technology. The problem with the oil and gas industry regarding this technology is that its parts are not standardized. Therefore, the ability to standardize products and drawings is the key to success when implementing AM in this industry. Standardizing will also be crucial if this implementation phase becomes a success right away or a longer and more complicated process. The quality of the new products will be the same or better than the original parts, since they use improved materials, designs and high-end production technologies. Increased quality, availability, and demand for this technology will lead to cheaper technology which means more available technology and lower product prices.

There is no prof or belief that this technology will stop its development in the market. Companies like Wilhelmsen support the development of this technology by continuously designing parts for AM and performing performance improvements. In addition, there could be a need for more standardization of the already existing parts.

Wilhelmsen is the AM-platform supplier or network registrar, which means they are responsible for the whole ecosystem. Their digital platform includes digital storage of parts that the production facilities can order and print globally through their AM production network. The platform will order parts, and the order will be sent by Wilhelmsen directly to the nearest production facility, which would be the base in Stavanger for this thesis. An engineering team from Wilhelmsen constantly works with OEMs, and they can also design parts directly from a customer's order if, for example, only parts of a machine break down at a platform. Products made from AM technology could be made with specialized materials that makes the process more sustainable. Such products can be reused, remanufactured, and repaired and could therefore be kept longer in the circular SC.
We expect this project to be up and running within a year, but this depends on the metadata and other crucial and time-consuming aspects.

6.3 Pros and cons of using AM-technology

	Transocean	Norsea	Wilhelmsen
Pros	- Reduced lead-time - Availability - Reduced storage on the platform - Sustainable aspects - Broken parts being reused or changed - Not dependent on fixed logistics	- Value creation - Cost-saving - Reduction of links in SC - Renew the SC - Sustainability - Reduced costs of leases and services - Increased number of satisfied customers - Less exposure to risks	- Shorter lead-times - Requirements from customers - Competition power - Availability - Reduce problems operationally - Reduced storage - Improved performance and quality
Cons	- Copyrights, patents, and TCO agreements	- Commitment - Investment costs - Legally	- Adoption - Competitive pricing - Spare part suppliers on board - Problems with some materials

Table 3: Pros and cons of AM-technology

The most crucial point for Transocean is the potential reduction in lead time. This reduction might prevent downtime, which they see as the biggest threat. Availability of critical elements will reduce items stored at the platform, which again reduces capital tied up in expensive spare parts stored for years. Reducing long-term inventory at the platform will prevent expired rights on the products and products being thrown away as a result of lost rights. Reduction in sustainable footprint will be a natural outcome of not transporting parts for long distances on land. Still, they are unsure if this benefit disappears in other CO2 emissions in the new investment. The last advantage they mentioned was that broken parts get fixed instead of rebuying the whole machine. This technique could even be a way of modernizing and strengthening the already existing parts. Today they are dependent on fixed schedules regarding transportation from the base with vessels and helicopters. Still, with this new technology and other technologies following, they could send only small parts with, for example, drones whenever needed. Challenges might be the copyrights required before printing parts that the OEMs owns, including patents and TCO agreements. They need to make new agreements with the OEMs to ensure quality and warranty on the latest products made with AM technology.

Norsea has a different point of view and information in this phase of the process and sees other benefits and potential problems with implementing and using this technology. The first benefit is the increased value creation within the supply chain. AM technology would be a cost-saving investment for the operators in Norway and globally, and reduce several links early in the supply chain. This technology will renew the whole supply chain and open for new opportunities, reach new goals and find new sources of income. One of these goals might be to become more sustainable or decrease the costs of leasing buildings or the services they would no longer need.

Additionally, delivering solutions with reduced lead time, costs, and reduced emission footprint are also evaluated as benefits. These benefits could lead to higher customer, SC, and stakeholders' satisfaction. The last benefit is less exposure to risks, which has a critical HMS perspective. Commitment and investments in this project, such as labor, investments and time used might turn out to have negative impact. This is only if they do not receive the benefits from this investment. Legally this might also be a challenge; all actors in the SC must evaluate ownership and responsibility. Processes they are making money on today are not a source of income many years ahead; therefore, changes and innovations are essential.

Wilhelmsen sees a pattern in continuous change, and they believe that within a 3–5-year perspective, the customers will no longer settle with long lead times from OEMs. Technology will exist, and the competition power of those who have it will be higher. These OEMs can deliver with shorter lead times, making them the optimal manufacturing choice. Availability is also an essential factor because it reduces demand for storage. Reduced operational problems is a directly result from increased lead time, and this is a crucial reason for why this technology is desirable. The overall performance will improve, both by the increased quality of the parts, increased time in circulation, and overall performance. The challenge is the adoption; how fast can a digital warehouse that is attractive and useful be formed? This element is crucial to gain any of the mentioned benefits. Another challenge is to get spare part suppliers in on the project, but there has been a positive response from the market. Finally, materials that are challenging to make is mentioned as the only technical problem. The biggest challenge is the cost of this, there will be better and more available technology in a few years, but there is a challenge to have competitive pricing today.

6.4 Why implement this technology now and not earlier?

Transocean describes how they have analyzed this technology for several years without finding it cost-efficient and available enough. Costs and availability are reasons why Transocean has not included itself in implementing this technology before now. Companies like Equinor had started with 3DP in Norway, and they already have small digital part storage, which can impact why others also have chosen to engage in AM technology implementation processes. Wilhelmsen describes maritime industries such as oil and gas as, in general, slow implementation of new technology. They tend to let new technology mature in other industries before looking at the benefits and exploring it. Companies such as Wilhelmsen will then be an essential part of the processes because they see the value and opportunities in this and have the knowledge and equipment. It is necessary to mention that AM technology is still in an early phase, but the market is more mature now than a few years ago. Wilhelmsen delivered 600 parts last year to maritime industries, and they have seen a high willingness to pay for these parts. Transocean recognize its most important role in preventing downtime, substantial economic losses, and the ability to come back to a mode where things move as they should as fast as possible when machines break down.

The media should also have some credit for this implementation. The potential benefits will likely influence industries struggling with long lead times, and specialized technical companies wanting to build a brand. Norsea sees the positive aspects of this implementation and wants to become more relevant from a service delivery perspective by focusing on the three words: smarter, safer, and greener. Smarter is implicit when discussing technology, but it also includes working for decreased lead- times and finding new solutions to cover needs in the market. There is also a potential to exclude links in the

SC regarding transportation and administration. This reduction will lead to an SC where money is used on value adding activities that rises the price of the product, rather than on non-value-adding activities. Reducing lead time by the three words presented, creating cost-effective solutions for the industry and reducing risks is why they chose AM technology. They are using helicopters to reduce the time it takes to deliver critical elements today, and this shows clearly, that they are willing to go far to reduce risks in the SC.

Sustainability is an essential dimension for technologies like AM, but efficiency and lead time are the most important from an industry perspective. Norsea describes economic sustainability as more relevant than just sustainability, because their economy is seen as necessary when making decisions and investing. Norsea explains this as choosing a project that increases efficiency, and positively impacts their economic growth. No business would start projects that don't pay off short- or long-term, and this is a phase few consider or forgets. Their reason for not evolving this earlier is the demand from the market. They need to reach the situation where demand and supply meet, which is the situation they are in now. The interaction between different technologies, such as 3DP, CNC, and machinery, has made it possible to print more extensive parts of the assortment and cover the growing needs in the industry. Fabrics with minimal need for personnel drifting and not just moving the totality through the SC have made it possible to create more value in this SC.

Oil and gas are not perpetual, and this technology is a way of preparing for a new time where oil and gas account for less of the revenues in this industry. This prospect means they have to work with alternative business opportunities because oil and gas are not a renewable energy source. Today they have an 80-20 distribution where oil and gas are responsible for 80% of the revenue, but renewable energy sources will be the 80% in a few years. This transaction has already started, and AM technology will input what they are already doing in this field. AM technology is an excellent enabler to cover the needs of the future with low cost and risks and is a part of the 2.0 Norsea business plan. The goal is to develop technologies and new renewable energy sources as their business area before Norway is out of oil and gas in the Norwegian territory.

7 Discussion

This seventh chapter is the chapter where findings are presented from the research perspective of this study. The discussion will build on the research questions provided: 1. How will supply chain management change after implementing AM technology? 2. How will AM be a technology that reduces risks in the supply chain? 3. What effects will this implementation have on supply chain performance? Finally, the findings will be considered with context, case description, and information provided through the theoretical framework on supply chain management and risk management.

7.1 How will SCM change after implementing AM technology?

Figure 16 shows the SC processes when critical parts break down. This SC is a linear chain that follows a fixed and linear way of ordering parts without much flexibility. The new circular supply chain is more flexible, and they use other materials, reuse, recycle, remanufacture and repair old parts to keep materials longer in the supply chain. However, they do not have all the necessary materials in every situation. It is in situations like this, things go slowly, and they end up in critical cases with potential downtime on the platform that is extremely costly (Sireesha et al. 2018).

Research from 2018 shows that other industries have been implementing this technology with great results (Sireesha et al. 2018; Ngo et al. 2018), but the Norwegian oil and gas industry has not played an essential role in this implementation yet. Both research and findings from interviews in this thesis explain why this is the case. The limitation related to types of materials is a crucial element of this discussion; back in 2018, only parts made of polymers, metals, ceramics, and their composites were possible to print. Therefore, businesses in the oil and gas SC did not see how this could benefit them and solve the problems they wanted to solve (Sireesha et al. 2018). To get the desired results, they need to put stakeholder assessment as a driver for organizations' effects (Spedding and Rose 2007). Stakeholders need to be involved early in the implementation process to prevent expensive adjustments throughout the project (Arnold 2020).

The new SC they want to have after implementing and including AM technology into their business processes is shown in Figure 13**.** This SC is called a digital supply chain; a network managed differently from the original linear SC. There is still a link between the actors in the SC, but the difference is that the new digital network is circular. A circular network such as this engages digital inventions, new technology, and better usage of the recourses they possess, including all supply chain links into a network. The most significant change is how they use, reuse, remanufacture, repair, and recycle old parts to keep them in the supply chain for a longer time. They will also change materials for some parts to make them more accurate, increase product lifecycle and adjust parts where they before would change the whole component or machine. Wilhelmsen will constantly work to improve the technology and engage more pieces in the digital storage. Which matches the literature that underlays that new practices and new technologies have continued improvements within the manufacturing areas (Gebler, Uiterkamp, and Visser 2014).

Reducing waste plays an essential role in engaging in a circular economy. The new digital network will work strategically to reuse old parts, rent out the i4 factory to other businesses and strengthen the material on existing parts to last longer (Stahel 2016). In addition to this, less long-term storage also prevents parts from breaking down or losing their warranty while storing them. This way of thinking and managing an SC results in the circular usage of its resources, and it plays a vital role in the implementation of sustainable solutions (Gebler, Uiterkamp, and Visser 2014). Fundamental reasons for engaging in AM technology are displayed by Stahel (2013) as *"you can ignore the transition into new technology for a long time, but when others in the industry succeed implementing it, you will no longer be able to compete against them."*

Findings from the interviews show how the new supply chain will centralize the production of critical parts to produce more products from AM technology. This is instead of having different suppliers and sub-suppliers for the various critical elements. The i4 factory will be closer to the end-user but still not at the end location for these parts. The location of the i4 factory does not correlate with Handscomb, Sharabura, and Woxholth (2016) say that the oil and gas industry is more decentralized. They want to build the i4 factory to print parts on demand instead of having different suppliers spread all around the Norwegian country and some other areas in Europe. This information shows that they will centralize the production of critical elements to the bases while still using the OEMs for other parts as they usually do. However, this will lead them to have the same decentralized structure as the theory suggests for all other elements, excluding the critical elements produced with AM technology.

They have been, for many cases, using the make-to-stock manufacturing strategy. Approximately 99% of all parts within oil and gas were gaining economies of scale in 2018 (Sireesha et al. 2018). There are some exceptions where they do not have the needed part stored close, and they end up in a risk situation where the lead-time increases drastically, and they lose money because of it (Arnold 2020). To prevent downtime, they have inventory holding costs on only one of the offshore installations worth around 10 million dollars (Van Mieghem 2011). They can reduce this inventory holding costs as more parts are able and profitable to produce in i4 factories. The planning horizon might also decrease because of this. Parts directly ordered from the i4 factory will not be as critical, and they can have a shorter time horizon than the five years they are planning in long-term planning today (Gebler, Uiterkamp, and Visser 2014).

Both literature and findings explain that this technology makes it possible to produce on-demand instead of storing parts for several years at a high price (sunn-tech ; Sireesha et al. 2018). By using AM technology in the manufacturing process, they will have either an ETO manufacturing strategy or an MTO strategy. The ETO is used when they need to make new digital files for a small component of a part, while an MTO strategy is used when they directly print the required part on-demand from customers (Arnold 2020). Christopher (2016) refers to demand network management, where the market and not suppliers drive demand. This technology will change the old way of looking at manufacturing strategies since the lead time will still not increase drastically compared to having the old make-to-stock strategy.

"The best supply chains aren't just fast and cost-effective. They are also agile and adaptable, ensuring that all their companies' interests stay aligned" (Lee 2004, 1). From the findings, we can see that decreased lead time plays a crucial role in this implementation. The ability to produce on-demand and produce what the customers want becomes more important. Both parts that are not produced by manufacturers anymore, and products where only one small part breaks down, make the lead-time long and essential in today's situation. Implementing AM technology ensures agility and adaptability, which is necessary for becoming more sustainable and gaining competitive power from delivering

future-oriented solutions (Lee 2004). The new solutions include making customized parts, standardizing existing components, and providing on-demand manufacturing.

The lean strategy is performed by specifying the value of their new service and identifying the value stream by adding more value to this service and SC by customizing virtually parts (Hopkinson, Hague, and Dickens 2006). Additionally, to create production flow both to and from the final upstream operator, letting customers pull by producing on-demand and perfect all links, are all elements in fulfilling all principles of a lean production strategy (Thangarajoo and Smith 2015). They are focusing on JIT to a higher degree than before by regular quality control by a technical and engineering specialized organization, focusing on efficiency in material flow, flexibility in the process, and focusing more on partnership and relations to other actors of the upstream SC (Arnold 2020). Using JIT should be more effective than the component substitution they have been using for years (Ho et al. 2015).

This implementation changes how they use their resources, dispose of their waste at the end of the product life cycle, perform transportation, and links they have in the supply chain (Linton, Klassen, and Jayaraman 2007). All these elements are ways of becoming more sustainable. By cutting transportation links and chose drones for last-mile delivery as a "taxi solution," they can achieve environmental benefits with a reduced CO2 footprint. Their social responsibility is performed by reducing people in critical manufacturing processes, and plan for future energy sources when oil and gas are no longer an option. Finally, their economic commitment is satisfied by making more money to benefit society. All these three elements of sustainability need to be balanced not to compromise the other (Faber, Jorna, and Van Engelen 2010). Within the interviews, I understood that sustainability comes as a bonus to some operators in this supply chain. Their main goal is to improve the performance of the supply chain and reduce risks, while the technical company focuses mainly on sustainability and possibilities in digitalization.

Research shows a trend in the oil and gas industry to renew their old processes and plan for a new energy world where no more oil and gas are in circulation. Statoil becoming Equinor in 2018 is an example of this new period where they work to become a market driver for new requirements (Ryggvik 2015; Equinor 2018). Equinor has a considerable influence on the Norwegian oil and gas industry. Norwegian base companies have also changed how they make money to compete in the market and reach the requirements of different stakeholders (Harangozó and Zilahy 2015; NorskPetroleum 2021b), and they focuse on finding solutions today that give them livability and the ability to influence the future. Today they produce 80 percent oil and 20 percent renewable energy, and energy consumption offshore was supplied by gas turbines (Korpås et al. 2012). In a few years, they will use more resources on energy from, for example, wind power (NorskPetroleum ; Mäkitie et al. 2019). AM technology is an essential element in the new TIR, where renewable energy empowers the economy (Rifkin 2011; Berman 2012). These elements are reasons for why this industry need to implement such advanced manufacturing technologies.

Output from interviews shows that they will cooperate and communicate more regularly and depend more on each other when AM technology is implemented. The collaboration will mainly be focused on in this process is the vertical collaboration that includes the platform, suppliers, base company, and technology company. This collaboration also includes internal collaboration, where they need to communicate more often because multiple functions and departments are a part of this new conversion (Barratt 2004). By looking at the literature, Simatupang, Wright, and Sridharan (2002) imply that the ability to synchronize interdependent processes, integrate information systems, and cope with distributed learning is required to build and maintain vertical partnerships in the new digital SC. Becoming partners, collaborating vertically, and integrating their SC will be crucial in gaining mutual benefits from sustainable solutions, and competitive advantage in the market (Spekman and Davis 2004; Barratt 2004). In addition to better being able to meet increased competition due to market globalization, stakeholders' requirements, international requirements, and scarce resources (Simatupang, Wright, and Sridharan 2002)

7.2 How will they work with risk management in the implementation phase of AM technology?

There is a broad agreement among literature, research, and oil and gas companies that long lead times and potential downtime are the most critical risks (Longwell 2002). The results of a risk factor or uncertainties might be positive; where they find solutions and prevent downtime, to a disaster, where the rig has an extended downtime. Researchers expect risks and uncertainties to have negative expected results, but some risk has opened up some positive opportunities to grow and gain knowledge (Spekman and Davis 2004). On the other hand, the potential outcome is potentially critical and destroying; and they are willing to go far to solve these problems. Risks and uncertainties are essential for businesses to understand and find possible solutions, to gain from the uncertainty. Instead of ending up in a critical downtime situation that could cost them millions of dollars from lost profits and costs.

According to Silva (2016) a limited budget is the reason why most drilling companies have not implemented applicable risk control measures. The limited budget makes it essential for SC within this industry to find specialized methods for risk assessments, analysis, and control over risks, especially human factors. In addition, Cort and Gudernatch (2014) also found that companies within the oil and gas industry find it hard to find common ground when assessing and quantifying sustainable risks against traditional financial risk systems. These are two reasons why this technology has not been executed yet, but it is also the reason for why they should implement it.

Downtime could be affected by both external and internal uncertainty (Kahneman and Tversky 1982). The external effects of a downtime situation could be bad weather conditions (Ryggvik 2015). Bad weather causes a longer last mil delivery time and potential damage to the transportation or ruined parts, such as when the first rig was badly destroyed when it crossed the Atlantic to the Norwegian continental shelf. (Ryggvik 2015). In addition to this, increased demand for renewable energy and increased competition is also external uncertainty they must consider (Shuen, Feiler, and Teece 2014). Internal uncertainties could be lead times in the oil and gas industry. Many things lead to long lead times but could be adverted by searching for new information and learning more about what's causing them. In this thesis, downtime is seen as a risk since there are only negative consequences from ending up in this situation (Hopkin 2013; Bisson 2014), while long lead times are seen as an uncertainty since there can be both positive and negative consequences from this situation (Bisson 2014). They could, potentially, use dynamic capabilities framework to recognize opportunities and mitigation strategies for risks in the upstream part of the supply chain. Using this framework could be a solution to understanding how uncertainties and risks can be positive, challenging, and growing instead of recognizing them only with the harmful consequences (Shuen, Feiler, and Teece 2014).

SCRM is explained by Jüttner (2005, 124) as *"managerial activity that includes identification and management of supply chain risks, through a coordinated approach amongst SC members, to reduce SC vulnerability as a whole."* This strategy combines risk management with SCM strategy and lets them work together within the SC to solve the risks and uncertainties together. Implementing this strategy has been an SCRM decision that includes multiple links in the upstream supply chain working together for the same goal. Their common goal is to reduce lead time to prevent downtime by using new technology such as AM technology implemented into the i4 factories. This cooperation is a perfect example of how communication and shared goals could result in more successful solutions and achieve positive ripple effects for all parts of the SC than if they had a single risk management strategy.

Cigolini and Rossi (2010) argue that different parts of the oil and gas industry are differently affected by operational risks and should have their own designed risk management process. By implementing the AM technology, fewer people will be directly engaged in the upstream supply chain operations. Fewer employees would lead to fewer injuries related to human factors, one of the primary injury incident rates (Norazahar et al. 2014). 80% of incidents related to human factors in drilling situations need to be reduced to become more sustainable (Zhou, Wang, and Zhang 2017).

The four staged SCRM strategies presented by Van Mieghem (2011) have already started in this innovation process. The first stage is to identify all potential risks and uncertainties. Some of the most critical risks and uncertainty appear in Table 4 (Ho et al. 2015). All these elements are related to long lead times and are risks they should focus on before implementing AM technology. They face both organizational and supply chain risks leading to long lead times and downtime disasters (Ho et al. 2015). Demand factors for SC could be information disruptions, bullwhip effects, and demand uncertainty (Cigolini and Rossi 2010). Demand uncertainty means they do not know when critical elements break down; for some parts, it can be multiple years between each time a part need to be changed. This prognosis makes it challenging to map what the demand will look like, and some parts even take weeks or months to produce. They could be unlucky and face a situation where they have stored a broken part or a part with expired warranty, and in such a case, the need for a new part is time critical. Operational risks could potentially end up in a bullwhip effect beyond actual effectiveness and efficiency reduction (Cigolini and Rossi 2010).

Demand factors	**Manufacturing factors**	**Supply factors**	**Information factors**	**Transportation factors**
Bullwhip effect	Inventory holding costs	Dependent on suppliers	Information infrastructure	Changed transportation modes
Demand uncertainty	Tied up capacity	Second-tier suppliers	Information distortion	On-time delivery
	HSE	Transit time variability		Supply chain complexity

Table 4: Risks and uncertainty faced in this SC

The inventory holding costs, only at one platform, are estimated to be up to 10 million dollars, which are resources and capacities tied up. Insecurity regarding safety in this SC's fabrics and transport stages is also crucial for implementing this technology. Today, they are dependent on both suppliers and second-tier suppliers when ordering a new part, and they are also facing transit time variability because of this. And they use virtual inventory to map different parts at different locations but see that these systems might lack some functions. They are also operating systems for communication through the SC when critical parts break down, leading to potential information distortion. The last factor of risks that affects the lead time is the transportation factor. Solutions to this could be changing transportation modes and which also decreases SC complexity.

The second phase of this SC's SCRM strategy is presented by (Van Mieghem 2011) as risk assessment and valuation. In this phase, they will divide the different risks into the categories s seen in Figure 18**.** Downtime is the risk with the highest priority regarding the potential damaging outcome, and this figure shows which elements they should focus on to prevent this from happening. The most critical elements are long lead times, focusing on researchers and the industry (Sireesha et al. 2018; Longwell 2002). In addition, problems regarding suppliers are described as critical by Van Mieghem (2011). Suppliers might not have all the needed parts or are not certified any more, increasing the lead time. Other elements with high impact but low probability are the macro risks, stock-out situations, and tied-up resources in storage.

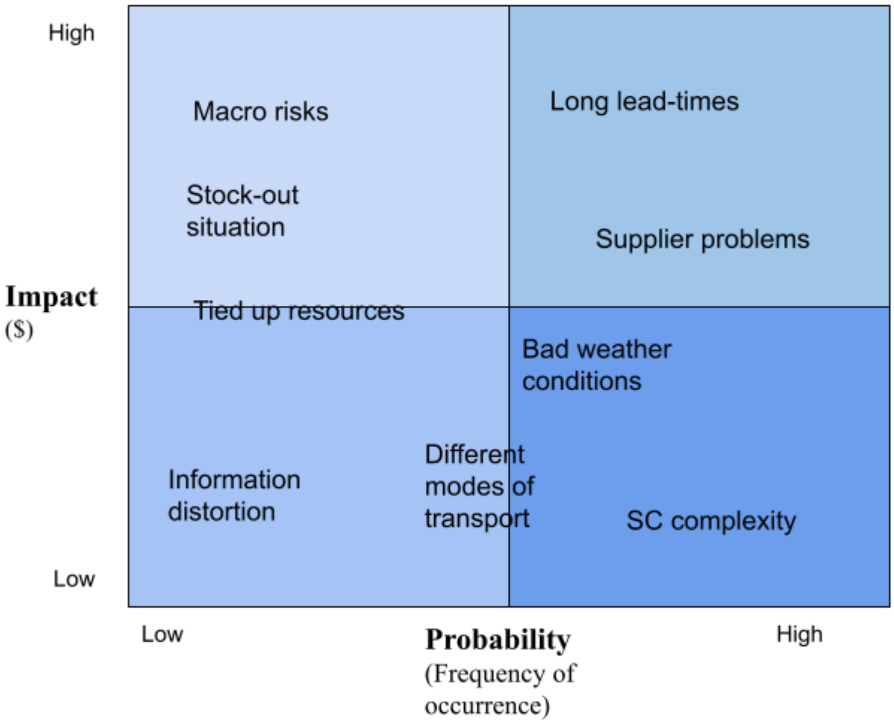


Figure 18: Subjective risks for oil and gas SC

The risks and uncertainties from the high and medium hazards are critical risks they will focus on and solve using AM technology (Van Mieghem 2011). They need to prioritize risk analysis and take thoughtful risk decisions in the planning phase, which means they have already made some of these decisions by choosing to move forward with the AM technology (Aven 2015). Carneiro, Ribas, and Hamacher (2010) describe uncertainty in the planning phase as reasonable since it is difficult to forecast all parameters, and point out the price of oil and gas, demand and supply as uncertain. There are multiple ways to make tactical risk decisions in this beginning phase (Fan and Stevenson 2018; Aqlan and Lam 2015), but the most suitable strategy based on the interviews is risk avoidance and risk-sharing. In addition to using a risk mitigation strategy to reduce risks in all decisions made (Fan and Stevenson 2018). By constantly monitoring risks, they reduce the chance of it occurring and the consequences (Norrman and Jansson 2004; Fan and Stevenson 2018;

Lenkova 2018). The chosen risk mitigation strategy needs to be specialized for this SC because there is no one-fits-all strategy (Talluri et al. 2013).

Risk avoidance is implied in situations regarding downtime on the platforms today. They would go far to prevent this, such as using helicopters as a transportation mode and keeping a tremendous number of resources tied up in storage. When implementing AM technology, they focus on solving risks all organizations in this upstream SC have, by sharing the risks vertically and with a third-party technology provider. Such strategies should be included in their strategic and tactical planning process to ensure that one risk decision might affect other risks (Aqlan and Lam 2015). AM technology is a part of a flexible risk mitigation strategy, and this is the most preferred strategy to achieve flexibility, increased responsiveness, and capabilities for this SC (Talluri et al. 2013). They are changing from a risk redundancy strategy with increased capacity, redundancy suppliers, and increased inventory to a situation where they find the flexibility strategy most preferred due to its efficiency (Talluri et al. 2013).

In addition to reducing lead time, reducing overall risks, and preventing downtime on the rigs, AM technology also needs to minimize sustainable risks. For example, the Norwegian state has implemented a TAX regarding CO2, which is the highest CO2 taxation globally, according to Celius and Ingeberg (1996). However, they also describe how this tax has improved production and energy efficiency. Therefore, sustainability is becoming an increasingly important topic (Hartman, Hofman, and Stafford 1999) and an increasingly critical issue (Hofmann et al. 2014). The SC should implement a SERM strategy that cooperates their sustainable risks into their SCRM strategy and overall business strategy. Working together makes them stronger and they could together work to reduce the chances the power of competitors and reduced taxes (Spedding and Rose 2007). In addition to the risks, this strategy will improve environmental elements to fulfill requirements from stakeholders and improve health and safety by fewer employees working in production.

7.3 Which positive effects will AM technology have on supply chain performance?

As the most crucial part, the positive effects for this SC from making the required changes are reduced lead-time and security against downtime. They would change the material flow line by decreasing non-value-adding activities and reducing the lead time by implementing advanced manufacturing techniques (Gebler, Uiterkamp, and Visser 2014). Reducing non-value-adding activities and waste in the SC will maximize the value of the final products, and these are essential elements in following a lean strategy (Wilson 2010; Sundar, Balaji, and Kumar 2014). This specialized parts make it possible to have an ETO manufacturing strategy without increasing the lead time and making specialized parts more available (Arnold 2020). The total supply chain will become more sustainable by switching to a lean business strategy where they focus on the reuse of the materials from old parts, eliminating waste from administration and transportation as well as maximizing the value of the products and services they deliver (Wilson 2010; Sundar, Balaji, and Kumar 2014).

The new manufacturing technique follows the JIT term of Lean strategy by improving the flow of these critical parts. Which makes them more flexible with ordering precisely the part of a product they need. Wilhelmsen will work specifically with quality management to improve materials and parts together with the approximately 40 suppliers they are working together with. Sireesha et al. (2018) argue that components made from AM could be lighter without compromising the strengths of the elements. For example, aluminum could become 45% lighter using this new technology. Additionally, they focus on partnerships, improving their overall performance (Arnold 2020). In 2018, only 1% of parts was profitable to make using AM technology, the reason is that most parts were benefiting from the economy of scale. For the first 5-10 years, they only focus the AM technology on critical parts. Today they believe that approximately 10% can be made by using AM technology, and this number is continuously improving as more actors implement it. It is an excellent strategy to start with only critical parts since they will continuously benefit from technology improvements, and the price of such specialized parts will continue decrease (Johannessen 2019). Additionally, making old parts with this technology could better utilize the machines, which also drives the prices down (Sireesha et al. 2018). and the total amount of profitable parts and parts that are possible to produce using this technology is improving.

They will gain from using a centralized structure for these critical elements from different OEMs. They use a decentralized manufacturing structure with multiple suppliers in several other locations, but essential elements will now be centralized at the i4 factories. Both the cost savings and reduction in the number of administrators are elements that indicate this. Furthermore, the adverse effects of this structure are minimized by the new manufacturing technique (Lee 2004). In addition to implementing a centralized structure for critical elements, they will continue with the known manufacturing for other non-critical parts.

The AM technology could be an SC risk mitigation strategy. The i4 factory is a solution to their high-risk, and medium-risk hazards. It reduces lead-time by reducing links in the SC, faster and more reliable products, and the facility will be closer to the end customers. This technology is more reliable when it comes to the time it takes to produce parts, since the risk of using several suppliers, and sub-suppliers are minimized (sunn-tech). Risks related to information distortion could decrease when they build partnerships and relations with the other organizations in this SC. By resolving quality issues and risks together, they create a partnership that will gain their long term (Charvet and Cooper 2011). Longwell (2002) argues that this SC also needs to make partnerships with the governments, because such partnerships is the key to success in investments. The Norwegian oil and gas industry is familiar with bad weather conditions, and all of its assets consider this (Ryggvik 2015). I have been assured that the quality of the products should be the same or even better than the old ones, and this is crucial in an industry where the products need to be stable even under extreme weather situations.

The overall SC performance will increase when implementing this new technology. Using JIT production makes the parts more available, and offshore storage decreases. Making it possible for the platform operator to have fewer recourses tied up in inventory, which directly decreases the 10 million dollars they have tied up today. JIT is also seen as a cost-efficient manufacturing strategy, making old parts more available with substitutes. Today's SC involves several suppliers and sub-suppliers, but they could potentially decrease the number of vendors involved with this technology. In addition, less documentation, less inventory management, and regulatory approvals positively affect the SC. All these elements are essential factors in decreasing lead time and averting downtime, which is one of the cost-saving operations within this industry (Sireesha et al. 2018). Norsea describes its future SC as a digital network or digital SC that matches this technology's multiple strategies and operations. JIT manufacturing processes, lean strategy, and sustainable future intentions are perfect examples of this. Hopkinson, Hague, and Dickens (2006) argue that introducing AM technology might cut costs and increase flexibility and productivity in manufacturing.

Implementing advanced manufacturing techniques will benefit from more innovative sustainable solutions (Gebler, Uiterkamp, and Visser 2014), and businesses interviewed in this thesis is far along in the process. According to Despeisse et al. (2017) they are moving in the right direction by implementing CE and sustainability into business values and procedures instead of letting AM technology be the complete change. The oil and gas industry has some challenges managing natural resources in deep water environments, and as a result, they would introduce conservation tools to address external challenges. These tools include encompassing regulations of the activities by controlling their discharge practices or material used, combined with avoidance rules, having some marine protected areas where they don't operate, and having temporal measures. Other projects show that conservation tools have a proven effect on their environmental management strategies (Cordes et al. 2016).

Lee (2004) underlines that agility, adaptability, and alignment need to be focused on to ensure competitive advantage and a long-term leading position regarding sustainability. Sustainable solutions will also give them livability and make it possible to influence the future as we enter the TIR (Rifkin 2011; Berman 2012). Stahel (2013) agrees with these phrases and even describes the transition as the only possibility. If another supply chain within this industry implements it, the ones that didn't follow will no longer be livable because of competition. The AM technology becomes a part of the new digital change, but this technology cannot be the complete change. Together with other technologies such as drones, they can make an SC that is more digitalized, sustainable, and circular compared to how they are performing today. New technologies and investments become vital if they want to compete, making them more productive and resistant to risks.

8 Conclusion

This chapter is a summary of the most important findings in this research with answering the research questions, along with presenting limitations and suggestion for potential future research within the same field. In this master thesis I tend to investigate *how additive manufacturing technologies such as 3D printing and CNC machines can reduce risks and improve overall supply chain performance in an upstream supply chain within the oil and gas industry in Norway.*

8.1 Conclusion

When implementing this technology, they need to find specialized methods for risk assessments, analysis, and control over risks, especially human factors in this industry. Factors, such as limited budget and trouble finding common ground when assessing and quantifying sustainable risks against traditional financial risks, has made it difficult to implement AM technology before. These uncertainties are why they have not implemented this technology yet, and it is also the reason why they should implement it. SCRM should be a strategy for risk management within the supply chain to work closely together to solve the risks and uncertainties, especially in an implementation phase. The timing for such implementation is perfect when they are working strategically against partnership and more robust vertical integration. Working together early in the process makes them more likely to find successful solutions and gain from positive ripple effects. They have divided risks into four categories and will focus on the risks with high possibility and outcome first, then move on to risks with either high output or high probability. The essential part of every risk strategy is to exclude downtime while cutting costs and becoming more efficient and prepared for risks that might affect their performance now and in the future.

The most significant change to the supply chain is that this technology is a part of switching from a linear supply chain to a circular economy. By implementing this technology, the supply chain will centralize the manufacturing of critical components, have an ETO manufacturing strategy for parts they usually store for a long time at a high price, and work more according to the lean business strategy. Reusing old materials, less waste, less misunderstandings because of many links in the supply chain, and being more sustainable are elements gained from using the lean strategy and a circular economy in combination. In addition, the just-in-time concept within the lean approach makes it possible to produce parts on-demand, which changes how they order, how technical departments work, and how they structure communication, risks, and planning processes.

Norway's oil and gas industry is in a critical time where changes are required to meet new possibilities for CO2-friendly operations in the future. Therefore, they are constantly looking for new ways of producing according to these requirements. Their overall goal is to find new sustainable production opportunities to reduce risks and stay in the market in the future. Stahel (2013) explains their need for change: *"you can ignore the transition into new technology for a long time, but when others in the industry succeed implementing it, you will no longer be able to compete against them."* Therefore, the vertical collaboration between suppliers, the base company, and the drilling company focuses on implementing new technology to stay competitive. The upstream supply chain will work closely together to cooperate on this new solution, "*The whole can be better than the sum of its parts*" Covey (1991, 7). Gaining partnerships, knowledge, and strategic position in the market are positive performance development from implementing such technology together.

Such an advanced manufacturing technique will play an essential role in the new circular economy and lean strategy by decreasing non-value-adding activities such as transportation and administration, which increases the total value of the final products. Critical parts will become more available, even if the OEMs no longer produce them. They can now produce components or only parts of the components with new specialized materials or old reuse of materials. In addition, they will have fewer resources tied up in storage, which decreases the costs of drifting, holding, and potential loss from products losing license while being stored. Fewer vendors involved in the critical supply chain leads, partnerships, and cooperation in this technology could lead to increased control over the situation when essential elements break down. Less documentation, less inventory management, and regulatory approvals are also positive effects of implementing such advanced manufacturing techniques to reduce risks, meet the needs of the future, and improve overall supply chain performance. They will also increase their sustainable performance by using techniques that are more CO2 friendly, decreasing waste and non-value-adding activities, and gaining a competitive advantage. This technology seems to be the future of the Norwegian oil and gas industry (Hopkinson, Hague, and Dickens 2006), but this technology cannot be the whole change and future alone. This technology needs to be supplemented with other technologies, such as drones and technologies for reuse of materials, to reach the optimal solutions.

8.2 Limitations

This case relies on the i4 factory's location at Hustadvika at the Norsea base. The site of the i4 factory has not yet been set, but recommendations and information are based on this requirement. This case is also limited to only the upstream part of the supply chain, and there will therefore be few interview objects, but they are all central and key persons from the different companies involved. I would have preferred to have more in-depth information about various parts and how the AM technology could decrease their lead time, risks, and environmental footprint. Still, this information was secret-stamped and impossible for me to get. In addition to this, I have had struggles getting in touch with suppliers. Communication from them could have given me both sides of this implementation, but this is not provided in this thesis.

8.3 Suggestions for future research

Implementing AM technology into the Norwegian oil and gas industry is still in the starting phase, which characterizes this master. But this opens opportunities in the first couple of years to follow the implementation process. For example, they could look at how they planned to do things theoretically and how they do things in real-time situations. A few years from now, when this technology is well established in the industry, it would be interesting to research the effects of this implementation and how the oil and gas industry has changed from making fossil energy to a more environmentally friendly approach. They are moving in the direction of becoming eco-friendly and digitalizing their processes. Still, it would be interesting to analyze the effects of their investments today on their performance in 5-10 years. As mentioned in this case, in 5-10 years, they would start to produce other parts than just the critical ones using this technology.

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10 Apprentices

10.1 Interview guide I

1. What are your responsibility when critical elements break down?
2. How will AM technology change how your everyday work is performed?
3. Why are you implanting this technology and why now?
4. Pros and cons with AM technology in the oil and gas industry?
5. What are the costs from storing parts and what will you spare from having spared capacity at the storage unit?
6. What will be the same as before, and what will change in the supply chain and its performance when implementing AM technology?

10.2 Interview guide II

1. What are your responsibility when critical elements break down what to do in those situations?
2. In which way will your work change when AM technology is implemented at the base?
3. Why are you taking a part of implanting this technology and why has this not been done before?
4. From your perspective, what do you think will be the pros and cons with using AM technology in the oil and gas industry?
5. What will be the same as before, and what will change in the supply chain and its performance when implementing 3DP?

10.3 Interview guide III

1. What is your role in implementing 3DP into the Norwegian oil and gas industry?
2. From your perspective, what do you think will be the pros and cons with using AM technology in the oil and gas industry?
3. From what you have seen from similar projects, how many parts, in percentage, can be printed today and in the future?
4. How will you work together with Norsea to together implement AM technology?
5. In your perspective, why are this project starting now and why are they far behind other similar industries when it comes to AM?