Faculty of Science and Technology

MASTER'S THESIS

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First off, I would like to thank the University of Stavanger for giving me the opportunity to get a valuable education. Through my five years at the university, I have gained important knowledge from competent lecturers and a system dedicated to their students.

I would also like to thank my supervisor Knut Erik Bang for great feedback. His inputs were crucial for the development of this thesis, and his critical questions made me especially aware of structuring and layout.

Lastly, I will thank my family and friends for the support throughout this journey. They kept me motivated and pushed me along the way.

II Abstract

The oil price drop of 2014 caused huge concerns for O&G (oil and gas) producers around the world, as their revenues suddenly fell rapidly. The high revenues of earlier years made spending into people and project unproblematic, even without profits in mind. When prices dropped, unprofitable projects and people were dismissed in order to reduce operation expenses to accommodate the new O&G prices. While this method is a fast and effective way of reducing costs, it will reach a point where no further discharges are possible.

Innovation is the next logical step for companies seeking to lower their costs. This process takes time, effort and knowledge, and the returns are uncertain. However, it could be a necessary step in order to survive in a competitive and volatile market.

Innovation often come from the use of technological trends, and this thesis explains the trends of *Automation, Big data analytics, Internet of Things and 3D printing,* and assesses opportunities within O&G drilling, production and transport where they can be applicable. The innovations I have selected within these trends: *Automation* – Automated drilling operations, Autonomous underwater vehicles and Autonomous transportation. *Big data analytics* – Subsea production systems. *3D printing* – O&G components production and On-site 3D printing. *IoT* – Pipeline inspection and monitoring and IoT as support.

Automation is a great way of reducing OPEX (operating expenditure) by reducing labor costs and human error related costs. The precision and speed of automated machines can outperform manual labor significantly, while keeping humans out of harm's way. Big data analytics will in the future become necessary in order to keep up with the amount of inputs and parameters of complex systems. It is then highly important to design a strong framework that can extract the most useful information out of the system, organize it and make decisions based on it. 3D printing has the potential to be disruptive in many aspects in the O&G supply chain. 3D printing's biggest advantage is availability of parts, as it can create parts on demand. This proves useful for lowering logistics costs and the speed of development of products. IoT is useful in a lot of machinery in O&G drilling, production and transport. It provides remote controllability, monitoring and updates, which can improve cost, efficiency and safety.

IV Table of Figures

1   Introduction

1.1   Objective

The objective for this thesis is to assess the opportunities of *Automation, IoT (Internet of Things), Big data analytics and 3D printing* in O&G (Oil and Gas) drilling, production and transport, and challenges in regards to managing and operating these innovations. The goals of these innovations are to improve aspects within the aforementioned O&G activities, most noteworthy in regards to *cost*, *efficiency* and *safety*.

1.2   Methodology

My main way of getting information is through internet searches on the topics. My sources include articles, statistics, surveys, academic papers, informative sites and online books. A big part of the theory in thesis is based on the book *The Management of Technological Innovation* by Mark Dodgson, David M. Gann, and Ammon Salter (2008). The book explains the theory behind innovation, and highlights how to properly manage technological innovations.

I have selected the technological trends of *Automation, IoT, Big Data Analytics and 3D printing* based on:
-   SCM World Community's survey on what technologies will have the biggest impact on performance in the manufacturing industries (figure 9) (Manenti, 2015).
-   Research on their role in current and future O&G projects.
-   My own assessment of relevancy for the O&G industry.

Furthermore, I selected the following innovations with the use of the technological trends above:

Automation	Big data analytics	3D printing	IoT
Automated drilling operations	Subsea production systems	O&G components production	Pipeline inspection and monitoring
Autonomous underwater vehicles		On-site 3D printing	IoT as support
Autonomous transportation			

Figure 1: Thesis innovations overview

I have selected these based on:
-   Current focus areas for O&G innovations
-   Current focus areas for innovation in other industries
-   Personal interests and prior knowledge on the processes involved

1.3   Limitations

In this thesis, I will not go into technical details about the technologies, but rather look at their functionality in general. I will base some of the arguments in this thesis on opinions from experts or managers and will therefore be subject to biases and opinions. The same goes for surveys and statistics, as they will come with their own biases and deviations. Due to the nature of new technologies and ideas, the theoretical improvements may differ from that in practice. However, I am assessing the improvement gains from these innovations through qualitative analysis and reasoning. Most of the comparisons and assessments are qualitative for the same reason. This thesis will not consider every opportunity for innovation, but only the one I have selected.

1.4 Chapter descriptions

Chapter 2 will explain some of the key theory behind O&G supply chain, O&G supply/demand/price/costs dynamics, as well as theory on innovation and the technological trends. This will serve as reasoning for why innovation is important in O&G today, and why the selected technologies are relevant for O&G innovation.

In chapter 3, I will go through these innovations in specific O&G operations. Here I will justify my selection of innovations, assess their advantages over present procedures and explain how one should utilize them.

Chapter 4 is about challenges and constraints of new technologies in general and within the specific innovations that I have proposed. In this chapter, I will go through the challenges of innovation and assess what may hold back the implementation.

In chapter 5, I will evaluate the pros and cons of the innovations to reach a conclusion for the value gains and limitations, as well as thoughts on time before they could potentially reach the market.

1.5 Background

Up until recently, the O&G industry has been prospering with high prices and a great demand for a while. This produced great revenues for all sections of the O&G industry. However, when the tides turned and the prices dropped in the early 2014, O&G managers could no longer lean back. Drastic measures where needed, and employees and projects were dismissed as a first level of cost reduction, and this is continuing even today (2017). Managers are realizing the need for innovation in order for profitability to increase within O&G companies. It is not only important for the firms themselves, but for whole communities and countries that rely upon the O&G income.

A big wave of technological innovations seems to be incoming, with advancements in computer technology as the driving force. These technologies opens up opportunities for a huge variety of innovations, that all industries should take advantage of, including O&G. Even though some of the technologies and ideas may seem a bit farfetched, one have to keep in mind that technology can move quickly. Early adopters of technology could really earn the competitive edge if executed correctly.

2   Theory

2.1   The O&G supply chain

The O&G supply chains are complex as they link multiple organizations and disciplines together. They cover the steps from the discovery of an oil or gas field to the fuel at the gas station or the gas in someone's house. The figures 2 and 3 are good representations of the steps and parties involved in both the O&G supply chains.
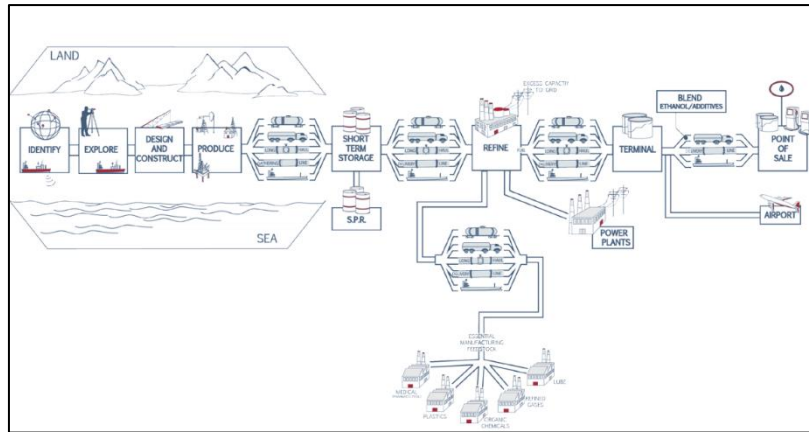
Figure 2: Oil supply chain (American Petroleum Institute)
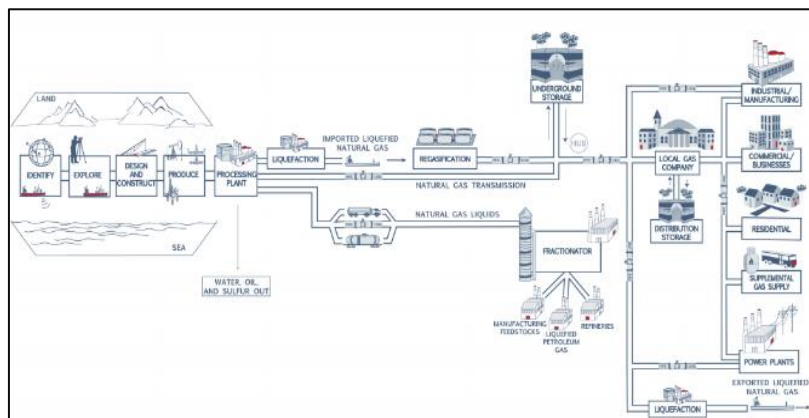
Figure 3: Natural gas supply chain (American Petroleum Institute)

The specific steps and methods are quite different in O&G industries, but the main features are similar: exploration → production → transportation → refining/processing → storage → distribution. In O&G business terms, the different positions in the supply chain are often referred to as *upstream, midstream or downstream*. The first steps are upstream O&G, which are activities such as exploration, recovery and production. The midstream sector is responsible for transportation, intermediate storage and in some cases processing. Downstream includes refining and marketing (Investopedia, 2015).

At the end of the O&G supply chains, you get fuels or usable products. The fuel types are mainly gasoline, diesel, jet-fuel, LPG (Liquefied Petroleum Gases: propane, butane) and kerosene (paraffin).
-   Gasoline and diesel are used in combustion engines mostly for powering vehicles.
-   Jet-fuel is fuel for jet engine airplanes.
-   LPG is mostly used for heating, cooking, cars and refrigeration

3

- Kerosene is used for the same purposes as LPG in addition to cleaning of oil-based products, pesticides and in chemistry.

Other products that stem from O&G are plastics, organic chemicals, lubrication and medical supplies.

2.2 The dynamics of the O&G industry

2.2.1 O&G Prices

The O&G industries are dynamic and complex systems. The oil price in particular has a strong tendency to fluctuate greatly. As I am writing this paragraph (April 5, 2017) the Brent crude oil price is at 54.6 USD/bbl (US dollars per barrel of oil) (Nasdaq, 2017), and just a week earlier the price was 2 dollars lower.

In order to evaluate the oil price of today, we have to compare it with previous values. A number itself will not give any clue of its current state, but a series of values will. Here is the 10-year history of the main benchmark crude oil prices.
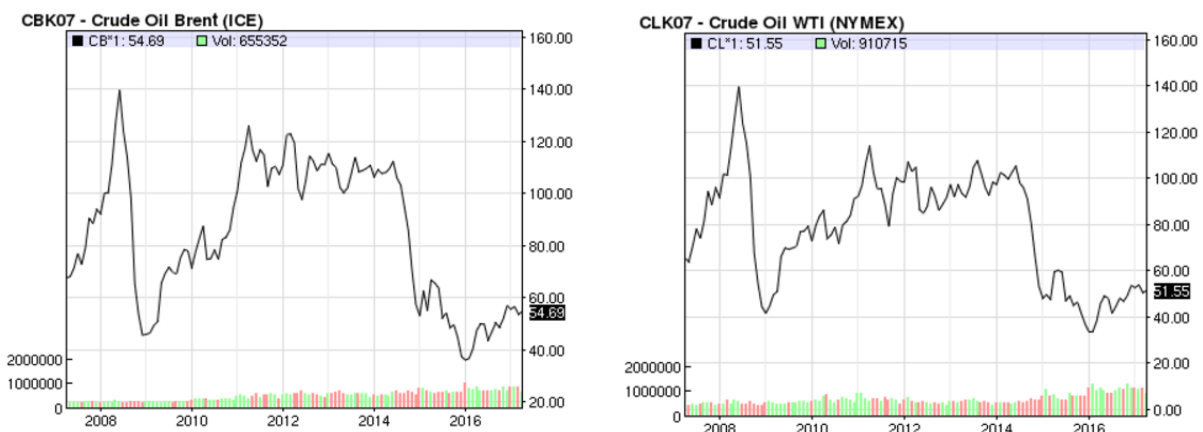
Figure 4: Brent & WTI 10-year crude oil price (Nasdaq, 2017)

Figure 5: Dubai 10-year crude oil price (IndexMundi, 2017)

Even though there are different benchmark prices for different oil varieties, they all seem to follow the same fluctuation pattern. This is due to the factors that influence these price changes, in which they all have in common. According to the U.S. Energy Information Administration, important factors are supply, demand, economic growth/decline and geopolitical and economic events (U.S. Energy Information Administration, 2017). Supply and demand are closely related, and have always been key factors for the price of commodities such as oil and gold, but in reality any product or service. Supply and demand is an interdependent dynamic system and one of the basic concepts of economics. Underlying drivers for supply and demand, as stated earlier, can be economic and geopolitical situations.

The recent drop in the oil value, compared to the relatively stable period 2010-2014, have significantly affected certain aspects of the world economy. Most noteworthy are the impacts

on countries highly dependent on their oil exports. Russia is one of them. With O&G accounting for 70% of their total exports and 52% of their federal revenue (U.S. Energy Information Administration, 2013), the recent price drop has caused significant reduction in the value of Ruble (compared to the USD) (XE, 2017).

Several sources claim that the oil price will have a steady rise in 2017-2018 that will continue for a while (Deloitte LLP, 2017) (World Bank, 2017). They claim that it will reach 60$/bbl in 2018 and 80$/bbl in 2030. However, due to the nature of the oil price, this can vary a lot, as unpredictable events can drastically change this.

The natural gas price follows the same fundamental principles of supply and demand. According to U.S. Energy Information Administration, these are the main drivers behind them:

Supply factors	Demand factors
Variations in the amount of natural gas production	The level of economic growth
The volumes of natural gas imports and exports	Variations in winter and summer weather
The amount of gas in storage facilities (referred to as storage levels)	Prices of competing fuels

Figure 6: Supply and demand factors for natural gas (U.S. Energy Information Administration , 2016)

Variations in seasons and temperatures in general causes demand variability for the natural gas. This is because of its use in heating and cooling in both residential and industrial contexts. Some major power generators have the ability to switch between gas, coal and oil as their fuel. This will cause a competition amongst these products that will affect their demands and ultimately their prices (U.S. Energy Information Administration , 2016).

2.2.2   O&G Demand

O&G are commodities that have had a steady increase in demand for a long time. According to the BP Statistical Review of World Energy (BP P.L.C, 2016), oil consumption has increased by a factor of about three since 1965, and it is expected to grow over the next decades. According to OPECs estimates (Organization of the Petroleum Exporting Countries, 2016) the market share for the demand of oil (compared with other energy sources) will continue to increase with 0.6 percentage points up until the year 2040.

The current energy market share for oil is at 31% and gas is at 22%, totaling at 53% (as of 2014). OPEC's estimate is expecting this total to stay the same until 2040, but gas is going to bypass oil in market share. The world's total energy demand is also on the rise because of population growth and GDP increase in developing countries. They are expecting some of the O&G demand to shift from OECD countries (referring to some of the world's most developed economies) to developing countries, while they are expecting other renewable energy sources to take some of O&G's market share in the OECD nations.

2.2.3   Cost of producing a barrel of O&G

Lower prices will decrease the profitability of the operations and they can stop investments in future projects, as they might not be profitable. Figure 7 shows the cost associated with O&G production for the major O&G producing countries.

Cost of producing a barrel of oil and gas

Average cash cost to produce a barrel of oil or gas equivalent in 2016, based on data from March 2016.

Note: Brent crude price as of April 7, 2017 at 1:07 p.m. BST.
Source: Rystad Energy UCube
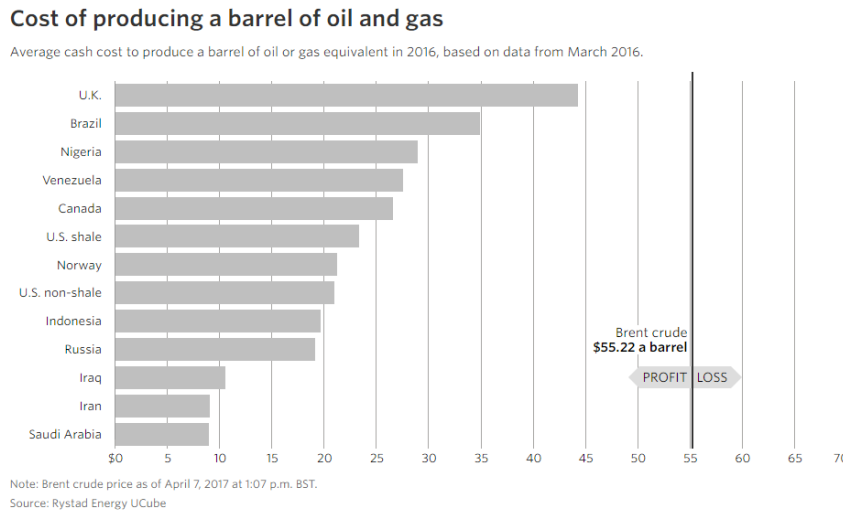
Figure 7: Cost of producing a barrel of oil and gas (WSJ news graphics, 2017)

This difference in cost of oil production is mainly due to CAPEX, OPEX and transportation method/infrastructure, which again depends on the location and the method of acquiring the O&G. As figure 7 shows, some countries and regions are more vulnerable to the O&G price in terms of reaching sustainable profits. The countries with the cheapest oil production, like Saudi Arabia, Iran and Iraq will have a gross profit of 45 USD/bbl when the price is at 55 USD/bbl, while countries like the U.K. will only gain 10 USD/bbl. This causes a difference in oil price flexibility amongst countries and regions, which has strong implications for competition between the major O&G exporters. Here is an example of profit margins for the most expensive oil (UK), the cheapest oil (Saudi Arabia) and one in the middle (US shale), and their relative profit margins.
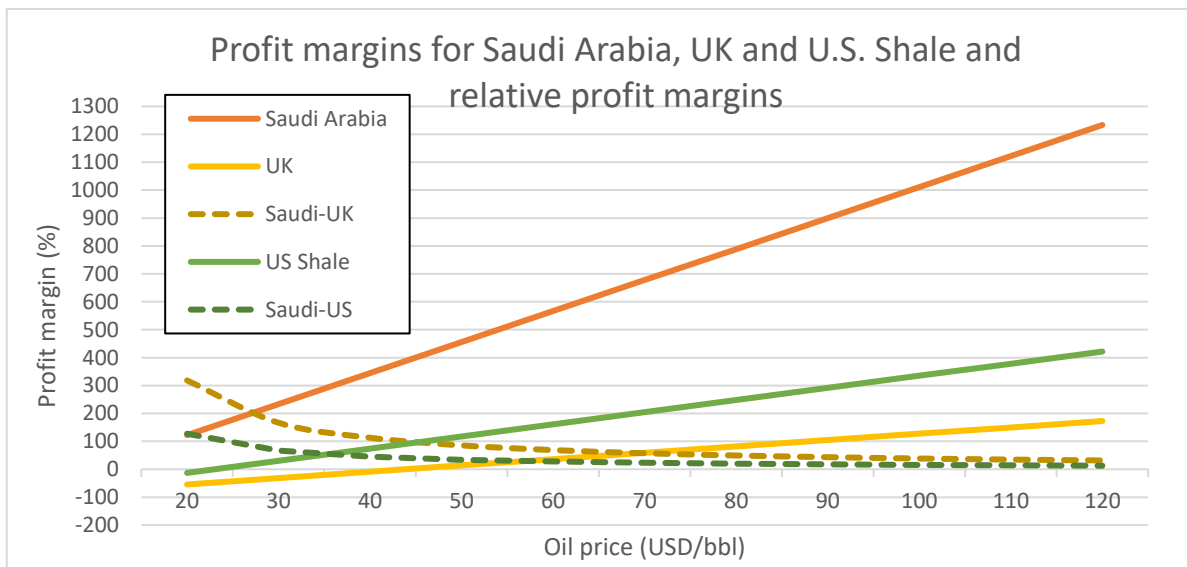
Figure 8: Profit margins for selected countries

When oil prices are low, the countries with the least expensive oil production will have a bigger competitive advantage over other nations, and when the price is high, they will be more similar.

2.2.4 CAPEX vs. OPEX

CAPEX and OPEX are two different types of business expenditures. CAPEX is capital expenditure and refers to investments into fixed assets, such as machines, vehicles and computers. They are bought for long-term use, and thus they are often depreciated over their expected useful life.

OPEX is operating expenditure, and they refer to expenses that covers daily tasks needed for operation. Depending on the operations, they can include costs such as power, material, maintenance, labor costs, supplies and insurance.
(Maverick, 2017)

2.3 Innovation

> *Innovation is much more than invention – the creation of a new idea and its reduction to practice – and it includes all the activities required in the commercialization of new technologies (Freeman & Soete, 1997)*
>
> *(Dodgson, Gann, & Salter, 2008)*

Innovation in practical terms is to use new ideas to create or improve things, which in return can create value. There is a distinction between the idea of invention and innovation. Invention on one hand is the act of creating a completely new product, process or service, while innovation on the other hand, is to create new or improve existing products with the use of current technologies. Often can innovation be a clever combination of technologies, or the use of certain techniques outside of its proposed area (Grasty, 2012).

Implementing an innovation includes scientific, technological, organizational, financial and business activities (Dodgson, Gann, & Salter, 2008). Each one of these activities are crucial for successful innovations and they require their own strategies in line with the overall business strategy. The complexity of innovating arises from the fact that they require all aspects of the firm. From the technology team that creates the solutions, to the financial department that evaluates the cost/reward.

Some innovations are described as *disruptive innovations*. These innovations shakes up the existing market by creating low cost high quality products for the average consumer. Disruptive innovators seeks to widen the market by challenging the existing market leaders with more available products. As a new technology is launched, we often experience a delay before the product is available to the general market. This is due to the initial price being too high and the target market being the high-end market. While low-cost versions can come early, they are not regarded as disruptive until they can prove the quality level of the major players (Christensen, Raynor, & McDonald, 2015).

2.3.1 Innovation in the O&G industry

O&G are continuous process industries characterized by a steady demand (Dodgson, Gann, & Salter, 2008). They are the two major energy sources of the world with no immediate threat to their dominance (Organization of the Petroleum Exporting Countries, 2016). This should provide a strong incentive for further investments into innovation and improvements to the operations, but it may as well cause the opposite. Managers may rely on the routines and processes that is currently effective, instead of investing in high-risk innovations that may or may not create additional value to the firm. With uncertainties regarding return on

investments, managers might be hesitant to deploy such costly innovations. However, due to the recent fall (and slow growth) in O&G prices, there is a strong understanding among companies that innovation may be key to profitability or even survival (Swart & Otremba, 2016) (Kleinschmidt, 2016).

Innovation in the O&G industry should not focus on the product itself, but rather the operations. For these industries, operations and processes are the features that allow for the most innovation, as it is here they can differentiate themselves from competitors by decreasing costs and increasing profits. There is no secret that the main driver for the O&G industry is profit. While there are numerous ways to achieve higher profits, the most obvious ones are to lower costs and increase performance. Innovation is a great tool for both these problems, but it takes time. When the oil price drops, companies' first steps tend to be laying off employees and scrapping unprofitable projects (Biscardini, Morrison, Branson, & del Maestro, 2017). This way of cutting expenses can only go so far. There comes a time when a firm has to innovate in order to ensure profits and competitiveness in the market.

Some key focus areas for innovation in today's O&G industry are:
- Lower recovery costs
- Lowering well construction costs
- Increasing standardization
- Exploration efficiency and cost
- Improve condition monitoring and maintenance in terms of costs, safety and efficiency
- Automation
- Making unconventional fields more cost effective
- Environmental friendly operations
- Improve safety

(Offshore Energy Today, 2015) (Kleinschmidt, 2016) (Swart & Otremba, 2016) (McKinsey & Company, 2014)

2.4   Technological trends

I could not find a clear definition of a *technological trend*, but a broad definition of a trend is *a general direction in which something is developing or changing* (Google, u.d.). If we include technology, we can say *a direction in which technologies are heading*. Technological trends follows a wave pattern (or phases) where one (or few) initial technological breakthrough(s) causes a cluster of innovations (Nelmia, 2015). According to Dodgson, Gann and Salter, we are in the period of information and communication technology, which followed the invention of the microprocessor, with the most noteworthy innovation of that period being the computer (Dodgson, Gann, & Salter, 2008). However, with the advancements in computers and robotics we are perhaps drifting towards a new age. Some examples of today's technological trends are increased automation/robotics, 3-D printing and artificial intelligence (Deloitte, 2017).
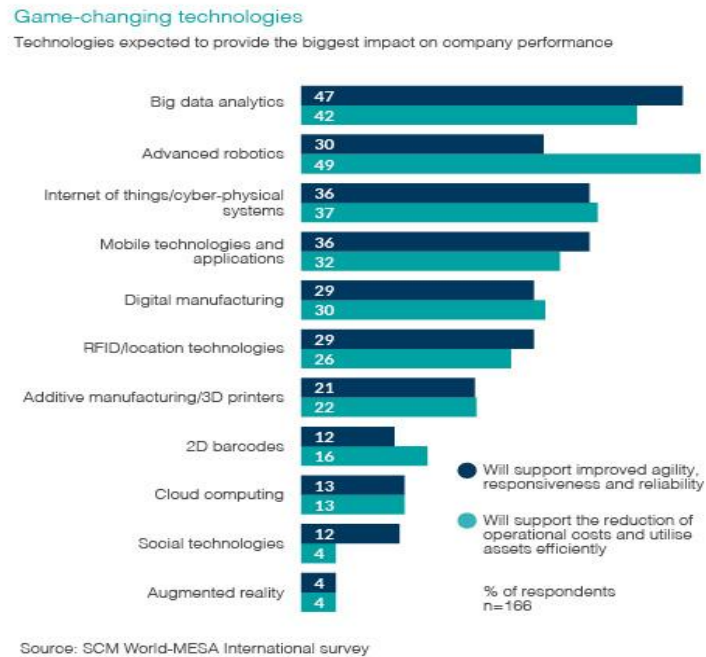
Figure 9: Technologies expected to provide the biggest impact on company performance (Manenti, 2015)

Figure 9 shows the SCM World Community's survey on what technologies will have the biggest impact on performance in the manufacturing industries (Manenti, 2015). As you can see, Big data anlytics, advanced robotics and IoT are the top three most prominent technologies for manufacturing, with 3D printing also ranking fairly high. These numbers are for manufacturing industries. However, it is reasonable to assume that they can be applied to O&G operations as well, since they both share the goals of lower costs, higher efficiency and better safety.

2.4.1 Automation

The word automation is, according to Merriam-Webster Dictionary: *the technique of making an apparatus, a process, or a system operate automatically* (Merriam-Webster Dictionary, u.d.). Either the automated system can replace the work previously done by a human operator, or it can do things not possible for a human operator (Encyclopædia Britannica, inc., 2017). In order to gain value from implementing an automated process, it needs to improve quality, cost and/or time efficiency. The degree of improvement needs to outweigh the investment costs and any additional operation costs. These costs consists of machine costs, installation costs, downtime during setup, training, condition monitoring, maintenance and more. This calls for a risk evaluation of the project. A successful implementation can increase production, decrease lead-time, increase quality/decrease variability of the products, decrease production costs, improve logistics, improve safety, and create new opportunities (Dodgson, Gann, & Salter, 2008).

The use of automation has greatly increased production over the last century. Early 20th century's mass production systems sparked a revolution towards automated systems and industries soon followed. With increased interest, new technologies arose, which further increased automation and further decreased the need for human interaction (Encyclopædia Britannica, inc., 2017). The trend of today is to implement fully automated systems, which can operate completely without human input. The goals of these systems is to reduce cost and raise efficiency.

9

Today you can see automation arising in many different shapes. Even by just observing the world around you, you can spot the trend of automation. Automation is replacing human labor in many areas, as for instance the automatic checkout systems at grocery stores are reducing the need for human cashiers. Automatic transportation is another example, as autonomous cars are slowly becoming a reality. Almost all major car manufacturers are working on their "driver-less" cars in a race to be the first and best. They are not far from reality. Tesla for instance, (as of October 2016) is already producing their cars ready for the future implementation of their autopilot systems. They will be gathering data from traffic before they fully implement their autonomous technology (The Tesla Team, 2016). The opportunities here are huge for many aspects of society, and not only for private consumers. Industries as well can take great advantage of this technology, with safety, cost and efficiency as key improvement potential areas.

The O&G industry is no different. This industry, as many other, strive to optimize their production process to create low cost and highly efficient systems. For this industry, automation can be a great tool for significantly reducing operating costs, thus gaining a higher profit margin for the products sold. In addition, removing operators from high-risk operations regarding O&G production can have a huge impact on safety.

The level of automation (LoA) is determined by the degree of human interaction. My basis for assessing LoA is with Frohm, Lindström, Winroth, & Stahre's: *LoA-scales for computerized and mechanized tasks whitin manufacturing* (Frohm, Lindström, Winroth, & Stahre, 2008). While this is a scale for manufacturing, it can be adapted to O&G operations. The table below shows the LoA, description and examples from manufacturing.

LoA	Mechanical and equipment
1	**Totally manual** - Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power
2	**Static hand tool** - Manual work with support of static tool. E.g. Screwdriver
3	**Flexible hand tool** - Manual work with support of flexible tool. E.g. Adjustable spanner
4	**Automated hand tool** - Manual work with support of automated tool. E.g. Hydraulic bolt driver
5	**Static machine/workstation** - Automatic work by machine that is designed for a specific task. E.g. Lathe
6	**Flexible machine/workstation** - Automatic work by machine that can be reconfigured for different tasks. E.g. CNC-machine
7	**Totally automatic** - Totally automatic work, the machine solve all deviations or problems that occur by it self. E.g. Autonomous systems

Figure 10: Level of Automation (LoA) (Frohm, Lindström, Winroth, & Stahre, 2008)

The term "Big data" is loosely defined, but it mainly means a large amount of data acquisition and storage. This gathering of ever-increasing volumes, varieties and velocities (the three V's) of data is due to the billions of people and tens of billions of devices that are interconnected. Rise in digitalization is a driving factor, as more and more "things" and people are becoming digital and connected to a network with constant data streaming (Press, 2014). The important value comes with handling of this data, and it can have strong implications for many industries, including O&G. The ability to extract the most useful information out of these huge data sets is what industries strives to optimize. Here are some examples from of different ways of utilizing the data that can be useful in the O&G industry (based on the article in Advanced Performance Institute):

Understanding and Targeting Customers

Info regarding purchase habits, location history, interests, and social network are stored within internet sites, internet providers and devices. Mass gathering and analysis on segments of target markets, can give indications of market needs and trends. Seeing patterns in these data sets will enable a business to create predictive models that can give a strong competitive advantage. With these patterns, you can improve products or services based on feedback without directly consulting the customers.

Example: A downstream oil company could invest in a new gas station in an area that has recently seen an increase in traffic, population and/or pressure on nearby gas stations. The increase may not even be evident yet, but big data analysts could be seeing subtle trends towards that area, which becomes an opportunity for the downstream oil company.

Understanding and Optimizing Business Processes

Big data analytics can give continuous info on customer stocks and better estimate sales forecasts to plan the logistics and delivery of products. This can enable you to reduce overall stock, plan production accordingly and effectively coordinate inbound and outbound logistics. Delivering just the right amount to the right places at the right time will lower logistics costs on both the receiving and delivering end. This will further improve lean production strategies with lower wastes, mostly in the form of transportation, over production and inventory (Arunagiri & Gnanavelbabu, 2014).

Example: Big data can help managing outbound logistics from a refinery or terminal. Predicting supply and demand at target points of sale and traffic in the area can help determine optimal volumes, routes and timing.

Personal Quantification and Performance Optimization

Assessment of personnel status through technologies like smartwatches/bracelets, has the ability to improve human resource strategies. Measuring employee's health and activity on a real-time basis can prove useful for both the workers and management. They gain valuable information that can lead to improvements in work environment, individual health and distribution of workloads, which ultimately can lead to higher performance of individuals and the firm (Bell, Lee: Wearable, 2016).

Example: Management of an offshore drilling project can see signs of stress or discomfort among the drilling crew through health measures such as heart rate or blood pressure. Without any of the employees willfully admitting to this, management could take actions to better the work environment.

Optimizing Machine and Device Performance

Monitoring of machines and devices is important as they increase in complexity and value. Monitoring can produce a substantial amount of parameters that can be hard to handle and interpret by humans alone. Analytics techniques can greatly improve the value of the information that monitoring equipment are generating. Smart structuring, filtering, weighing (and more) of information, can help management make good decisions based on machine performance. Big data analytics can capture and collect information from other machines of its type or machines operating under similar conditions, and look for performance patterns to find root causes of possible deviations.

Example: Gas production could be subject to decreased flow in the pipelines and faults in any of the system components could be responsible. Big data analysis could collect data from all the condition monitoring equipment and find errors that are hard to identify by directly looking at the numbers. Furthermore, when the failure is located, it can identify the possible failure mode that enabled this, which can be a complex combination of circumstances. (Marr, Bernard: Advanced Performance Institute, u.d.)

The 3 V's I was referring to earlier are challenges that management of big data faces. Managing these properly is critical in order to take full advantage of the technology, but that is not necessarily an easy case.

Volume

The volume parameter is simply the accumulation of the shear amount of data from multiple sources. This will start stacking up in databases and servers that will create a higher demand for data storage space. Accessing the relevant data for the relevant task is increasingly challenging as the volume increases, which requires some serious sorting and structure in order to make the data easily available for both computers and humans.

Velocity

The challenge of velocity comes from the fact that data is coming from all the sources at increasing rates. Handling constant streams of data can be challenging for the processors, sorting system and operator. Real-time data streaming is only useful if you are able to interpret it in near real-time as well, and this creates another challenge for management. Fast incoming data is therefore both an opportunity and a threat to a firm (StateTech, 2013).

Variety

Data comes in a whole bunch of varieties, from simple text sheets to video, and even within the same type of files, they can have different format. Managing these varieties is imperative in order to get any useful information out of the data. This is especially true when you are attempting to compare data of different varieties, as they can indicate a pattern that evolves from the same common sources (Maronde, 2014).

(Gewirtz, 2016)

*"The Internet of Things (IoT) is the network of physical objects or "things"
embedded with electronics, software, sensors, and network connectivity,
which enables these objects to collect and exchange data."*

(International Institute for Analytics, 2015)

Internet of Things (IoT) is one trend you can easily notice in everyday life. The so-called "Smart-things" are all under the definition of IoT: Smartphones, -watches, -TVs, -houses, -cars, even whole cities (Vermesan & Friess, 2014). It seems like the possibilities are endless. The features they have in common are network connectivity, sensors and software. This network of everyday devices can make you able to monitor and control them without physical interaction, like unlocking your house from work or preheating your car. These consumer market products are great for daily tasks as they increase comfort, lower effort and reduce time for doing simple tasks, but these advantages are more comforting rather than having any significant value (International Institute for Analytics, 2015).

In the industry however, the applications of IoT are much more valuable. Using network connectivity in machines, equipment and people could increase performance measures greatly in a firm. Noteworthy are the opportunities to monitor multiple parameters of machine performance with sensors that can stream data on a near real-time basis. This technology in contrast to, for instance semi-automatic in-hand condition monitoring equipment has the ability to detect performance errors and defects earlier and more accurate. In addition, operator are not even required to be in contact with the machines, which can have strong safety implications (International Institute for Analytics, 2015).

Other uses of IoT can be
- Location of products and people. One can track incoming/outgoing transport to better predict and plan for deliveries. This can have good implications on timing during project, where you are awaiting materials from suppliers.
- Equipment status. Check whether equipment is in stock or in use, and where it is located. This is great for the overall logistics performance.
- Workplace environment. Sensor could get data on air quality, hazardous gases, temperature, lighting and more. This could improve overall work condition or detect possible leakage of gases.

(Vermesan & Friess, 2014)

IoT is a very broad term that influences most other technological trends today; including the ones I am studying in this report.
- Automation makes great use of IoT through digital sensors, smart technologies and network connectivity.
- Big data analytics is to some extent, the management of IoT data (see 2.4.3.2).
- 3D printing can use IoT technologies for remote operations.

Network connectivity can be great for updating software wirelessly. Like with for instance mobile phones, computers and even cars. Software in modern cars can receive updates through Wi-Fi or cellular connection to improve its performance and user interface (Taub, 2016). This technology is applicable in other industries as well, and can be usable in future machines and devices.

2.4.3.1 Information value loop

From Deloitte University Press' article on IoT in O&G, they introduced a good visual representation of the use of IoT. They call it the information value loop. This shows the movement of information through a system with IoT as the enablers. It represents the algorithm for the potential value gains of IoT technologies if handled correctly. Executing every stage of the information value loop properly is key for an efficient use of IoT information, and the focus point for further improvements should be with the bottleneck stages (Slaughter, Bean, & Mittal, 2015).
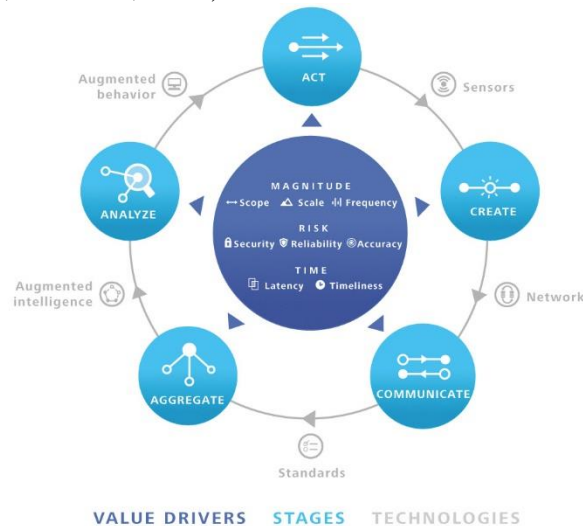
Figure 11: The information value loop (Slaughter, Bean, & Mittal, 2015)

*"For information to complete the loop and create value, it passes through the loop's **stages**, each enabled by specific **technologies**. An **act** is monitored by a **sensor** that **creates** information, that information passes through a **network** so that it can be **communicated**, and **standards**—be they technical, legal, regulatory, or social—allow that information to be **aggregated** across time and space. **Augmented intelligence** is a generic term meant to capture all manner of analytical support, collectively used to **analyze** information. The loop is completed via **augmented behavior** technologies that either enable automated autonomous action or shape human decisions in a manner leading to improved action."*

(Slaughter, Bean, & Mittal, 2015)

2.4.3.2 Distinction between big data analytics and IoT

The distinction between these two terms seems a bit blurred. They are both new concepts and therefore do not have clear definitions. They both address data and things that creates and gathers data. From studying different sources on these topics I have seen some mixing of these terms that have been a bit confusing. However, for this thesis I will base the difference upon Tamara Dull's description from SAS' article on the topic:
- Big data is only the data being generated, thus big data analytics is the analysis and handling of this data.
- IoT are the objects that generate the data and their networks.
  (Dull, 2014)
- The more "things" you add to a system, the more it drifts towards big data analytics. Then the challenges of IoT becomes the challenges of big data.
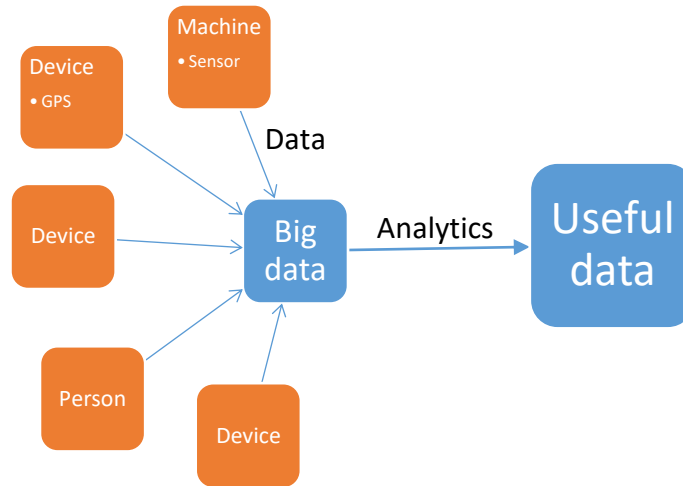
Figure 12: IoT and Big data relationship

2.4.4   3D printing

3D printing in its most general sense is to create three-dimensional objects with the technique of additive manufacturing. Additive manufacturing is adding layer-by-layer of thin material in order to create the desired 3D physical object. 3D printers have been around since the 80's, but it is not until recently that the technology have shown the potential to become a disruptive innovation (3D Printing Industry). The rise in 3D printing's popularity stems from the companies that recently made them publically available with affordable prices. Modern 3D printers range from industrial sized to desktop sized, and with price ranges for all types of consumers. Objects can be printed in several materials, with the most common being plastics and metals (including alloys). The use of plastics is mostly to create prototypes and other items that do not require specific material properties, while metals are for industrial or durable products.
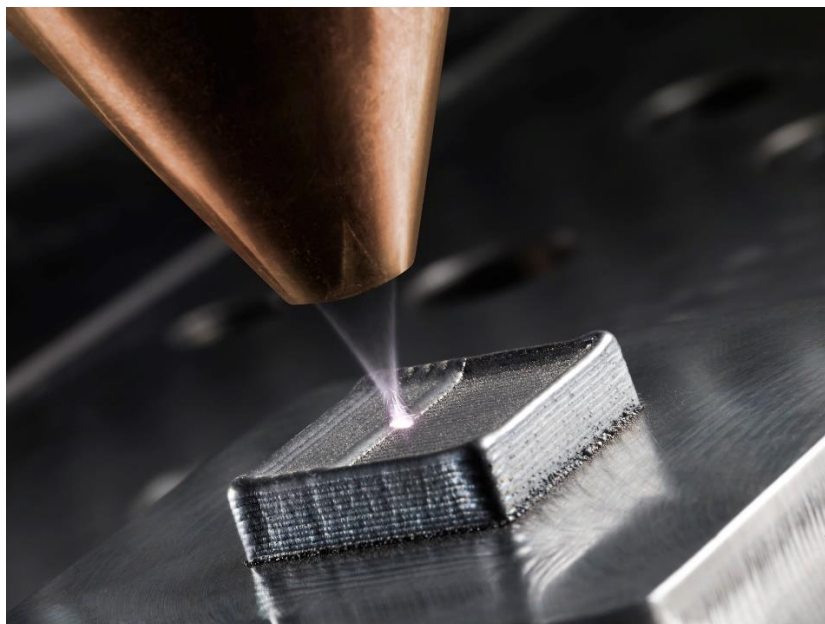
Figure 13: Metal 3D printing (Wired Island International)

Industrial 3D printing are seeing great potential to become widely adopted within several industries. Two-thirds of manufacturing companies in PwC's survey said they have already adopted 3D printing in some way, while another 24,7% said they plan to in the near future (PwC LLP, 2014). Furthermore, the consensus among the companies surveyed was that the *"Sweet spot in 3D-printing is in low-volume, highly specialized products"*¸ and that it is not yet ready for mass production (as of 2014). The speed and cost-efficiency of 3D printers are not yet there to compete with standard mass production processes. However, its ability to create specialized products with fewer steps in the supply chain is great for low-volume customer-specific products.

Specialized parts and tools are highly common in the O&G industry, so 3D printing could prove itself as a great asset. 3D printing could potentially eliminate the need for spare parts, as it has the possibility to produce these on demand. This is not until 3D printers could demonstrate the material quality, efficiency and reliability of current production systems, as O&G operations require robustness to weather, stresses, corrosion etc. imposed on its structure and machines.

3   Opportunities for innovation

Based on the technological trends mentioned above, I will put forward some innovations for O&G drilling, production and transport. These innovations could generate great value to the firms involved where current methods could be lacking. As mentioned earlier, the goals of these innovations are to reduce costs, improve efficiency and improve safety.

3.1   Automation

Automation can be a great tool for lowering OPEX for O&G operations, which is one of the main goals in the stable, low O&G price future. Reduction in OPEX is due to automation's ability to replace human workforce and thus removing labor costs accordingly. Additionally, automation can raise efficiency and safety with the removal of human limitations and error modes.

Automation can improve performance in the individual steps in the supply chain, but it can also improve the movement between them. Integrated automation across the supply chain can increase the flow of both product and information, such that it reduces lead times, intermediate storages and communication issues. A key potential for automation is the safe movement of O&G, by reducing the potential for human error along the way.

Not only is automating operations important, but also being able to handle the automation is vital for the efficiency of the systems. In the upstream O&G in particular, it is a driving trend to increase the standardization of automated systems. Being able to connect multiple components from various manufacturers seamlessly has the ability to increase performance drastically across the whole O&G industry.

3.1.1   Automated drilling operations

Manual labor have been used for most drilling operations for a long time. These are considered dangerous, and physically and mentally demanding. The industry has coined the phrase "roughneck" for a worker of such tasks. A documentary on the Alexander L. Kielland accident (major oilrig capsizing accident in Norway 1980) describes the harsh conditions of being a roughneck during that period. Noteworthy was the statement that it was common for the workers to be missing a finger or two because of these operations (NRK, 2013). Automation is a great tool in this case for reducing the risk to people and property.

Hard tightening/loosening of drilling pipes are now commonly done by so-called "iron roughnecks". They replaced the manual tightening with higher efficiency and safety. In a reporting from Bloomberg, they estimated that the process with this machine reduces the work force from three to two operators (Bloomberg, 2017). The iron roughnecks are typically controlled close by or in a control room with a LoA at around 5, but there are opportunities for higher levels of automation here. Robotic Drilling System AS (RDS) have developed the world's first complete integrated automated drill floor system, with four different robots capable of completing most day-to-day drilling tasks. They can operate autonomously or with additional control options for special tasks and circumstances (Robotic Drilling Systems AS, u.d.). This is huge in terms of safety, as drilling/workover/well services account for 22% of the fatalities in the upstream offshore O&G (OGP Safety Reporting, 2011).
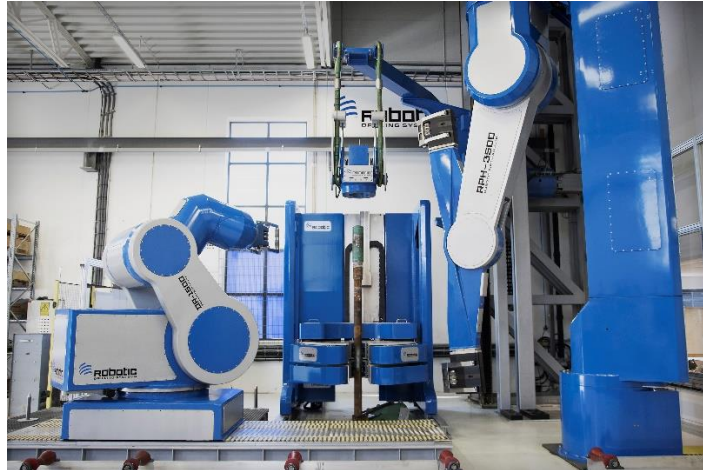
Figure 14: RDS AS autonomous drilling robot system (Robotic Drilling Systems AS, u.d.)

Further innovation on these systems are more intricate with RDS already showing a level 6 or 7 automation, and have already delivered one of their products while planning additional deliveries to the market (Robotic Drilling System AS, 2016) (Stavanger Aftenblad, 2015). One opportunity for further innovation is to make the robots more multifunctional, thus decreasing the number of robots. You can save a lot of cost and space by having fewer robots to do all the tasks. Furthermore, with fewer machines, you can simplify the manual/semi-automatic control system when special tasks or tests are required, or when exceptional conditions are present. This can reduce the complexity, number of operators required and time for the operation, all with their own associated risk and costs.

The table below is my assessment of the cost differences between automatic drilling – manual drilling, and automatic drilling equipment – iron roughneck. These numbers are my assessment of what degree selected costs associated with an automatic drilling in comparison to manual drilling and iron roughneck drilling (Range: -3, 3. Positive numbers indicates higher costs for automatic drilling).

Associated costs	Manual	Iron roughneck	Notes
Unit	2,3	1,2,3	Depending on the maturity of the market
Equipment	2	2	
Upgrades/repairs	-	2	
Personnel	-3	-2	

Figure 15: Automatic drilling cost comparison

The investment cost into the automatic machine will undoubtedly be higher. The difference however, will decrease as time goes on, when competitors enter the market to drive prices down. The additional CAPEX can be a deterring factor for management especially in days of low oil prices. They might not risk possibility of whether the long-term profits (in terms of lower OPEX) will cover the investment cost.

Additional equipment to the automatic drilling machines will include control equipment, maintenance equipment and repair equipment. These will have an additional cost associated with them, which are higher than the other options, or not even included in the other two. Technological machines like the automatic drilling robots will require advanced supplementary equipment to control, maintain and repair.

Upgrading and repairing procedures are more intricate with higher levels of technology. It is natural to assume that maintenance would be conducted more often when you have invested in an expensive machine. In addition, the automatic drilling robots will require additional maintenance and upgrades its software. All these maintenance and upgrade procedures are essential to maintaining performance and the useful life of the machines.

A typical drilling crew, according to Schlumberger's Oilfiled Glossary consists of eight roles for drilling operations around the clock (Schlumberger Oilfield Glossary). The cost benefits of not requiring a drilling crew can be significant for the OPEX of drilling operations. The more automatic the system is, the fewer operators you will need.

3.1.2   Autonomous underwater vehicles (AUV)

Autonomous underwater vehicles (AUVs) are independent self-controlling underwater vehicles capable of doing tasks below the surface. The term autonomous refers to a system that is capable of adaptive learning and problem solving without input from a human user. The distinction between automation and autonomous lies within the guidelines for the machine. An automated system follows coded instructions while autonomous systems can make decisions based on the situation presented. This makes AUVs ideal for underwater operations. As of today in the O&G industry, AUVs main tasks are mapping of the seabed, pipeline inspection, structural inspection, geological surveys and general surveillance (Kongsberg Maritime, u.d.) (C & C Technologies, u.d.). The main advantage for the AUV are the range, both depth and horizontal distance. Since AUVs are battery driven, they can travel very far from the deployment site, but limited operation time due to battery capabilities. This is the tradeoff of using an AUV compared to a tethered ROV (Remotely Operated underwater Vehicle). The ROV receives the power and data through a tether, which in turn limits its range. State of the art AUVs like Kongsberg's Hugin claims it can operate for 100 hours at 4 knots (7,4 km/h) which gives it about 370 km max range (considering a roundtrip) (Kongsberg Maritime, u.d.).

The trend of more sophisticated automation and robotics creates opportunities for innovation for the AUV. The AUV can expand its utilization to more than just observational tasks. A work class ROV uses manipulators (arms) and tools to perform underwater tasks such as maintenance and repair on pipelines, subsea installations, retrieval of items and wellhead work. The ROV excels at these tasks due to the skilled operator controlling it and its six degrees of freedom maneuverability (see Figure 16). The ROV is on a 5 or 6 LoA, depending on the type. Some ROVs are specialized for pipeline repair for instance, thus giving it LoA 5, while the more all-round work class ROVs are at 6. The goal for the AUV is to have a level 7, fully autonomous vehicle with no operator and the same maneuverability as a ROV. In a study into these kinds of AUVs (Ridao, Carreras, Ribas, Sanz, & Oliver, 2014) they found what they call I-AUVs (Intervention AUV), that demonstrates ROV like capabilities. While still under development, they have been able to turn valves, autonomous docking into docking station and recover objects. The ability to do these simple tasks shows great potential for innovation.
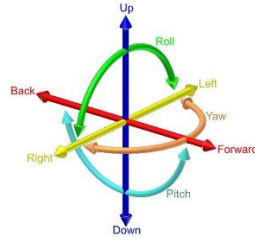
Figure 16: Six degrees of freedom (Wikipedia, 2010)

Figure 17: Girona 500 I-AUV (Palomeras, Ridao, Romagós, & Vallicrosa, 2014)

As stated earlier, an innovation needs to improve valuable aspects. In this case, cost and efficiency are the most relevant ones. Through my study on the matter, I have come forward with a table representing possible cost benefits/disadvantages compared to a work class ROV. I assume that both are of similar quality and that the AUV are able to do all the tasks currently occupied by a regular work class ROV. These numbers are my assessment of what degree selected costs associated with an AUV in comparison to a ROV (Range: -3, 3. Positive numbers indicates higher costs for an AUV).

Associated costs	Value	Notes
Unit	0,1,2	Depending on the maturity of the market
Equipment	-1	
Maintenance/upgrades/repairs	1	
Personnel	-1	Includes wages and training

Figure 18: AUV cost comparison with ROV

The unit cost is hard to assess and varies a lot, but for the same quality and purpose, I would assume the AUV price would initially be higher. As mentioned earlier, newer technologies and especially highly technical like this, tends to enter the market with a high price while they drop when competition increases (Dodgson, Gann, & Salter, 2008). Therefore, when the market matures and the product is becoming more available we can expect a normalization of the price, maybe similar to that of an ROV.

Opportunities for lower equipment cost and storage space/cost exists for the AUV. As an ROV requires control equipment, an AUV can get away with computers for pre-/post operation analytics. Some of the most advanced ROVs even requires whole control rooms or modules (Oceaneering International, Inc., 2010). Vehicle tools, maintenance equipment, repair equipment and spare parts will be more or less the same.

Maintenance, upgrades and repair are essential steps to increase the useful life of an asset, which is especially important for a costly investment. Upgrades for software and hardware will possibly increase its cost, as systems that are more complex require high degrees of expertize and more intricate procedures (Dodgson, Gann, & Salter, 2008). The same applies for repairs.

The AUV's lack of human input requirements is a significant cost benefit, as an ROV will require multiple people. For instance, renting a work class ROV in Europe from Oceaneering requires three people at least, at the minimal total cost of over £2000 for a 12-hour workday(as of 2010) (Oceaneering International, Inc., 2010). Likewise, if the firm has their own permanent ROV team, their wages are also an additional cost. In this case, training and lessons may also be required on a regular basis in order to maintain or improve the skill level of the operators.

Automation in this case can greatly increase the efficiency, accuracy and reliability of the tasks. Since human error is inevitable, limiting the possibility of it occurring can be beneficial. An autonomous machine can do well-known tasks with better precision and speed undoubtedly (Haight, u.d). However, the unpredictable nature of the sea will require the AUV to have a response to all of the possible situations. A skilled human operator would be able to make decisions based on intuition and judgement even in unfamiliar or sudden situations.

Safety is not a significant improvement for AUV, considering that ROVs do not impose any significant safety threats. According to the OGP safety reporting, diving, subsea and ROV activities accounted for only 1% of fatalities and 0,5% of lost work days in the offshore upstream sector (OGP Safety Reporting, 2011).

3.1.3 Autonomous transportation

Transportation is a part of several steps in the supply chains as shown figure 3 and 4: from production to storage, storage to refinery, refinery to terminal and terminal to market. Depending on location of start and end, the methods of transportation are mainly ships, trains, trucks or pipelines. Ships are obviously transporting O&G from and to offshore fields, as well as across oceans. Trains are used for onshore long distance transport. For short distance travel within urban areas to points of sale, they use trucks. Pipelines are useable in both sea and land transport, and in contrast to the other methods, it carries a constant stream of O&G.

As mentioned earlier, autonomous transportation can be a great asset for many industries, and I see the biggest potential in regards to road transport. According to Forbes, tanker trucks account for the highest amount of crude oil spills among the transportation methods commonly used (Conca, 2014), and some (if not most) of it is due to human errors. The damage is not only imposed on property and cargo, but also people, as Forbes ranks automobile accidents as the number four activity likely to kill you (Conca, 2012). Statistics from *Federal Motor Carrier Safety Administration* showed that the driver was the primary cause in 87% of registered severe truck accidents in the US (Federal Motor Carrier Safety Administration, 2007). This shows a clear potential for improvement and an opportunity for

innovation. If the autonomous transportation becomes a reality, and the roads are filled with autonomous vehicles, we could potentially see a big drop in accident rates. Significant costs will go down because of lower accident statistics, like for instance: Risk is a strong factor for insurance companies to base their premium rates. So lower risk, lower insurance costs. Another important benefit to consider is reputation. It is beneficial for the whole industry if they clearly show initiative to improve their safety, and back it up with numbers later. This reputation applies to the public, government institutions and investors.

An increase in performance is also likely to come with this automation, and I see the biggest potential in availability. The ability to launch and deliver cargo without having to be dependent on a driver to be accessible can really increase efficiency. No matter where you are in the supply chain, whether delivering or retrieving the products, you can place an order that can immediately start driving towards the destination. The retriever can place orders any time of the day as long as there are available transport vehicles.

Variability in supply and demand exists in all parts of the supply chain. The production site might produce more or less O&G than expected, then the scheduled transport would either not have enough capacity or depart not fully utilized. An automated on-demand ordering system can reduce the need for intermediate storages and can ensure full cargo loads, while also decreasing delivery times.

The same benefits apply for rail and sea transport. Rail is arguably easier to automate, since the movement is much easier, back and forth. The traffic system on rail is also way less complex than that of the road. In comparison to truck transport, human error accounts for only 33.5% of the train accidents (87% for trucks) (Wieand, 2016), which will make autonomous trains less impactful than truck automation, but significant nonetheless. However, the amount of crude oil a train (consisting of 100 train cars) could carry is around 350 times the amount of a truck (70 000 bbls for train, 200 bbls for truck) (Conca, 2014), which drastically increases the value of the cargo.

This volume is only a fraction compared to the biggest "supertanker" ships in the world. They can carry around 2 million bbls of crude oil, 30 times that of a train transport, further increasing the cargo value. In the Forbes article comparing the different modes of crude oil transport, the author wrote the following regarding tank ship oil spills: "*I still don't understand why these keep happening with modern technologies to detect water depth and nearby boats. Human error needs to be better removed from this equation*" (Conca, 2014). To what degree the author understands the intricacies of operating such vessels is unknown, but the idea is that human errors can occurs even when strong barriers are in place. Automation is in that regards, the strongest barrier there is to avoid human error.

Associated costs	Value	Notes
Unit	0,1	Depending on the maturity of the market
Equipment	0,1	
Maintenance/upgrades/repairs	2	
Personnel	-3	

Figure 19: Autonomous transport costs comparison with current transport

The unit cost is, as with all next generation technologies, going to be higher initially. However, due to competition that already exists among car manufacturers on driver-less cars, the unit cost may see an early decline.

Autonomous transport may require additional equipment for remote monitoring of their fleets. Even though it may not be required, it can be beneficial for analysis and further improvements. One can look for ways to optimize routing, timing and intelligence of the system. This investment into equipment may pay back in the long run.

A cost that may increase with autonomous transport is maintenance and repair. It will require higher levels of expertize to conduct maintenance and repair on the vehicles compared to regular trucks, trains and ships of today. The mechanic profession required for modern day vehicles is well established and widespread, but it may be lacking knowledge to operate on future software based transport. This will add costs and expertize requirements to future maintenance of autonomous transport.

Removing one operator from truck transport will make a significant difference in terms of labor cost. According to ATRI's (American Transportation Research Institute) survey on operational costs of trucking, they found that driver wages and benefits accounted for 34% of OPEX for American trucking companies (American Transportation Research Institute, 2014). Similarly for freight train transport, 36,7% of OPEX is labor associated costs (Kriem, 2011). If we consider the stage of development, where autonomous transport is without the need of a driver or supervisor in the vehicle, then that are the actual labor cost savings in the firm.

3.2   Big data analytics

O&G systems are getting increasingly complex with the increase in technology. Big data analysis can enable completely new perspectives on O&G optimization, with focus on condition monitoring and control of the devices.

3.2.1   Subsea production systems

Subsea production systems are great tools for making small and/or unconventional O&G fields cost-effective. These systems ties multiple wells and production systems together to one single output/input that either goes to a platform or straight to land. Subsea systems allows for the placement of production systems that are normally topside on a platform, on the seabed, such as separation, compression, pumping, power supply, and water and gas injection (Technology strategy for Subsea Processing and Transport, 2006). Subsea technology has made it possible to extract O&G from small and otherwise unprofitable fields with less dependency on the location of a platform unit. Subsea production could see great use in harsh environment like artic and deep waters, where ordinary platforms are impractical or unsafe. However, with an increasing number of components in these systems, the need for better handling and analysis of data emerges. Optimizing the production efficiency will require the best-in-class equipment. Being restricted to one manufacturer's equipment due to compatibility problems, can prohibit your ability to optimize. The nature of competitive markets may limit the ability to integrate properly. This will then requires efficient big data analytics for the volume, velocity and variety of incoming data from the subsea production units.
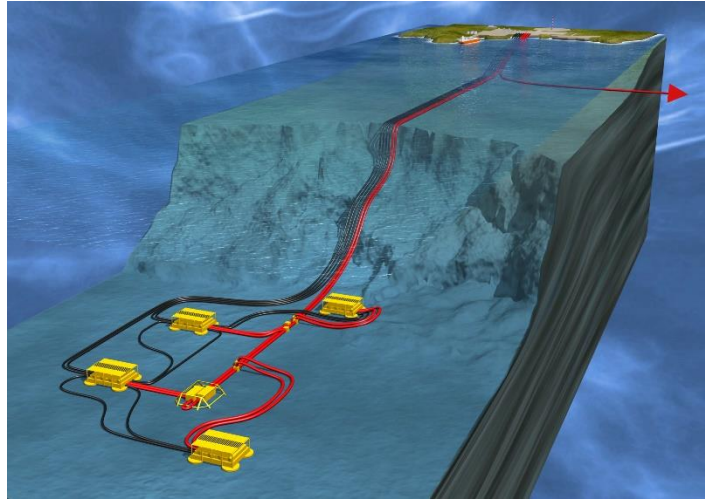
Figure 20: Ormen lange Subsea field (Nugrohoadi, 2008)

The importance of big data analytics solutions is huge with subsea production systems. The number of wells, sensors, production units and data parameters are increasing, as well as the complexity of these technologies. An opportunity for innovation is creating an efficient big data solution for all these types, regardless of manufacturer or component, emphasizing the optimization of the way you gather data, monitor and control the subsea elements (Bonner, Colpo, Moody, & Rogers, 2015).

Gathering data from a high amount of sources requires both robust hardware and software solutions. With standardization of the output parameters, the data could be easily organized and analyzed in real-time. An automated system would be able to filter the more important and immediate data in order for both itself and an operator to act upon when needed. The automated data gathering system will have to be able to produce highly comprehensible data sheets for later analysis, which could be key for improving performance. In addition, analytics could foresee possible events before they happen based on historical data and trends, which otherwise would not alert an overseer.

Monitoring the different elements will be increasingly harder as you add more sensor and measurement equipment. This is also necessary in order to ensure availability of the system, indicating possible performance errors, which if detected early can avert severe problems. Here is where big data analytics excels. By monitoring all the components simultaneously, an automatic system could take action on the relevant components, while keeping the others operational to maintain production. Real-time big data analytics would be able to respond faster to abnormal sensor readings than a human and find root causes.

The control solution should be comprised of automated controls and human oversight, which will combine the efficiency and precision of computers with the judgment, intuition and decision making of a skilled human operator. The control layout and user-interface should be comprehensible in a way that require the minimal amount of people. According to Bonner, Colpo, Moody & Rogers, controlling the subsea components through a common platform will reduce response time significantly, as it would not have to go through layers of data conversion (Bonner, Colpo, Moody, & Rogers, 2015). An automated system should be able to adjust the components independently to ensure performance measures such as, optimal flow and power consumption.

3.3   3D printing

As I stated earlier, 3D printing is a huge opportunity in the O&G industry. In some parts of the supply chain, 3D printing has the potential to be disruptive. The 3D printer's most valuable aspect is efficiency, with the ability to create on-demand products, have less dependency on third parties, have lower storages for spare parts/equipment and have increased customization capabilities.

3.3.1   O&G components production

For the sector of the O&G industry that manufactures the products used in O&G drilling, production and transport, 3D printing could serve as a great asset. Products produced for O&G operations are often highly technical and specialized with an expensive price tag as a result. As with most manufacturing processes, the end-product is often a result of parts, materials and processes from multiple sources and suppliers.

In every manufacturing process there is an additional cost added to every step of a product's supply chain. Therefore, reducing the number of parties involved in creating a product is both more efficient and less costly. 3D printing could eliminate some of these parties by giving more flexibility to the end distributor. The optimal solution for the end producer is to create most of the product in-house, while ordering as little as possible, for instance only purchasing material and electronics. This way, they lower wait time, lower surplus parts, lower possibility of wrong order, lower "middleman costs", less assembly work and increasing product flexibility.

In the development phase in particular, 3D printing can be an important tool for prototyping, with the ability to produce prototypes for testing considerably faster. This is also evident through PwC's survey, where prototyping was the number one area of use by 3D printers (PwC LLP, 2014). Flexibility is perhaps the most important factor here, as you can easily change out or modify a few parts while testing your product. With 3D printing's ability to change between materials, you can test different material options rapidly, to investigate their properties in practice.
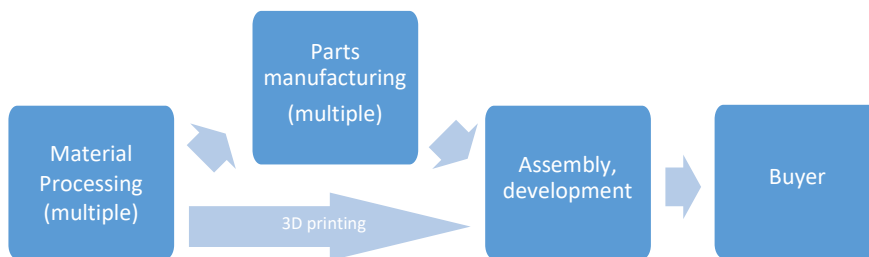
Figure 21: 3D printing's effect on supply chain

The figure above shows how 3D printing can shorten the path of a products supply chain. This generalized depiction of a products supply chain describes in this case, how a product moves from material → parts → assembly → O&G buyers as finished product. 3D printing can skip the stage of acquiring parts from third party manufacturers, by making these themselves. If we consider numerous revisions and alterations during development that requires new part orderings, the gains of 3D printing increases in both time and cost savings.

These cost reductions will be beneficial for the buyers of the O&G products. Development costs will add to the final price of the product, and thus CAPEX increase to the buyer. 3D printing in the future might be the big driving force for the efficiency to develop other innovations. With the shortening of development time and lower costs, we could see an increasing rate of innovations when 3D printing has matured.

3.3.2   On-site 3D printing

Reliable and fast 3D prints can prove to be valuable on-site in O&G operations. 3D printing has the potential to reduce the need for storage of spare parts to a minimum when the technology reaches the desired level of precision, reliability and speed. Storage space is a significant logistics cost for any manufacturing industry in both space utilization and handling. This is especially important for offshore O&G, because of space constraints in all types of drilling or production units.

3D printing can also reduce the direct cost of acquiring spare parts. 3D printing can replace or improve two ways currently used for acquiring spare parts: ordering beforehand or order when needed. Operations will most likely include both of these, with the most critical parts being the ones available at all times. Ordering beforehand will increase the availability of the operations in terms of lower downtimes, by having available parts on time in case of repair. On the flipside, it will also cause stocking on items that may rarely be used or perhaps never, which will increase stock costs and space. The other option is to order parts when needed. This will decrease stock levels, but increase the downtime between time of failure and time of delivery. The effectiveness of the two options will be dependent on the location of production relative to point of order. Operations in remote areas will suffer more from not having available parts, and this is the case for most O&G operations. 3D printing can be an alternative for effective spare parts management.

Effective 3D printing will enable you to create parts on demand when needed, or prepared in time for scheduled maintenance. Downtime during repair in this case, is only the time needed for producing the parts and the replacement itself. The time and cost benefits will rely on the speed and costs of 3D prints, which will most likely improve in the future.

New logistics problems will arrive with the handling of the materials for the 3D printers. However, due to the multipurpose properties of the materials, it will most likely be more efficient than current logistics structures. Materials could take up as much or more space than regular spare parts, but bulks of material are likely to be more easily and more efficiently stored with the right logistics management.

One can argue the case of safety as well. Especially in offshore operations, where winds and sea motion can send small objects flying. "Struck by" incidents accounts for the highest percentage of both fatalities and lost work day cases (OGP Safety Reporting, 2011). Struck by incidents are defined in construction as "*[…]forcible contact or impact between the injured person and an object or piece of equipment"* (Occupational Safety and Health Administration, 2011). It is uncertain how much impact removing some spare parts will have on these statistics, but it can potentially improve a great deal of it.

3.4   IoT in O&G

There are strong applications for IoT technologies in processes, machines, operators and systems in O&G operations. IoT does not generate value by itself, but rather serves as an opportunity to gain value. The creation of value is through utilization of the data from IoT, which means you need other processes to access and take advantage of it. All of the automation innovations mentioned in this thesis uses IoT technologies for daily use, and could potentially increase performance with higher levels of IoT.

3.4.1   Pipeline inspection and monitoring

Pipelines are one of the main transportation methods of O&G, and according to Slaughter, Bean & Mittal they are seeing an increase usage rate especially in the US (Slaughter, Bean, & Mittal, 2015). The shale oil boom have increased the liability on the US pipeline systems with increasing rates and variations in grades and volumes. This will call for a better systematic condition monitoring of the US pipelines system. Another concern for the health of pipelines that is relevant everywhere, is their age. Since pipelines are static structures, they are experiencing aging that is weighing heavily on their reliability. Increasing rates of failures are a consequence of the lifetime of an asset. So the older the pipelines get, the more they need maintenance in order to function properly.

IoT can be a great tool for maintaining pipelines. Sensors can keep track of important parameters, such as flow, pressure, vibrations and temperature. They can indicate possible leaks, clogging, material defects and seismic activity. Handling this valuable information correctly is imperative for the usefulness of the IoT, or else they are just expensive equipment not fully utilized. By handling, I refer to the networking and analysis of these sensors. The more sensors and equipment you add to the system, the more the systems move towards big data analytics issues. At some point, an overseer can no longer monitor the amount of data that is coming from the system, efficiently. Some algorithm must be in place to systemize the data to gain its valuable information.

Since pipelines often are buried and/or submerged, the maintenance and repair can require intricate and expensive operations. Reliable sensors could ensure a more cost effective maintenance schedule by basing it on actual condition numbers, instead of periodical plans that could have the risk of either conducting maintenance when not needed or being too late. Both these scenarios add costs: unnecessary maintenance and spill/leak associated costs. The risk of spills and leaks should be a significant incentive for increasing monitoring, because it can add "clean-up" costs, environmental damages and reputational damages.

Other than sensors, drones and AUVs could help investigate long sections of pipelines. They can use visual inspection to detect leaks, abnormal temperatures and structural defects such as corrosion and cracking, without the need for a human inspector (Penza, 2015). Their use is however limited to above-surface pipelines, as they need a clear line of sight. These in combination with sensors and analysis could produce a great condition monitoring overview of whole pipeline networks that could significantly increase maintenance operations.

3.4.2   IoT as support

IoT in O&G is not something completely new or revolutionary. Digital sensors have been around for a while, monitoring flow, temperatures, stress/strain, corrosion and more, but the idea of a network of IoT's that are constantly communicating is seen a huge opportunity. Attaching network based sensors on high value machines or equipment could really improve availability of the machines, in terms of preventive maintenance.

Automation makes use of IoT data to lead decision making, whether by a machine or a human. Readings from sensors, visual data from cameras, positioning from GPS etc., are all IoT technologies that automation in O&G could take advantage of and use to generate decisions. As machinery gets digital and automated, the need for strong sensors, software and smart decision algorithms increases, since the machine is expected to use the data to generate decisions by itself.

Automated drilling equipment needs strong sensors for precision during tasks, and in the case of RDS with four autonomous machines, the connection between them is highly significant in order for the machines to operate fluently together. In addition, condition-monitoring sensors should be in place to keep track of the state of the machines with real-time updates and analytics.

An AUV is already packed with sensors and software, so the IoT improvement potential lies within the quality of the sensors and the software. Better IoT in AUVs could improve readings and decision-making for the vessel, making it "smarter".

Autonomous transport could make great use of positioning and status analysis for management to monitor and control the transport fleet remotely. Management could use analysis to improve the system further.

Connecting digital machines to the network could enable rapid software updates and calibration. Software updates are forms of maintenance of software, and contributes to keeping it bug-free, secure and performing optimally. Having an up-to-date system will increase efficiency and safety of the operations, and network connectivity will ensure speed and convenience in conducting these updates.

4 Challenges and constraints

Innovations can come with a great deal of challenges and constraints. This is because neither the industry nor society is fully prepared for the implementation of these technologies. Challenges can come from handling of the innovations within the firms, skepticism/risk evasion from decision-makers or constraints from regulatory bodies. Overcoming these challenges can be difficult, and despite an effort to try, time can be the only determinant factor in some cases. Some of these challenges are external, and it limits the firm's ability to influence them, like social and regulatory challenges.

4.1 General

4.1.1 Reliability

Reliability is important for many machines and devices in O&G systems for several reasons, such as:
- They can be costly investments
- They often have a long expected lifetime
- They can be highly important for operations
- Downtime could be very expensive

Uncertainty regarding reliability is strong for new products or technologies as they lack service time. The product is likely to undergo long periods of testing during development phase, but it is hard to account for all possible hazards. Even regular environmental impacts could be hard to simulate. It is therefore natural to assume that this uncertainty can inhibit the adoption of new technologies, and management would rather stay with the procedures that are currently working.

Reliability in sensors could also be of great significance. Wrong indications of performance parameters could generate incorrect errors that could lead to wrong decision-making. A faulty sensor could be hard to detect if the fault is incorrect readings, and it indicates errors in the system.

4.1.2 Knowledge

In order to utilize a technological investment to the fullest, the company would need knowledge and expertise surrounding the asset. Requiring the needed knowledge is not necessarily an easy task when it is concerning new technologies and ideas. These new technologies would need time for studying to gain full understanding of potential and limitations. Management would also need knowledge of the innovation and understand the procedures in order to structure the operations around it effectively. Developing knowledge within the firm is also an option, by delivering lessons and courses to the employees from external experts.

4.1.3 Impact on organizational structure

Businesses aiming to adopt new technologies might have to restructure the organization in response to the technology. Innovations that changes the operations drastically will to an even higher degree require restructuring. It is natural to assume that when assets require deep knowledge and expertise, management would have to leave more decision-making to the experts, in order to optimize operations. Experts might be better at optimizing than management in these situations. Communication between people of different backgrounds and expertize will be highly significant to cope with the intricacies of the technology, as the technology might require people from several fields.

Along with innovations comes new job positions and removal of old positions. This affects both management and the employees. Management would have to restructure or create departments of the firm and assign positions, while simultaneously reposition or dismiss employees. This period of restructuring might take time to optimize.
(Dodgson, Gann, & Salter, 2008)

4.1.4 Investment costs

All innovations come with some form of investment, financial or non-financial. The automation cases in this thesis would come with a significant financial investment costs. In times of low oil price, costs of innovations like automated drilling and AUVs will have a great impact on budget. In order for management to invest into expensive equipment like that, they would need strong evidence for the OPEX gains, return on investment and other financial and non-financial gains in relation to the asset. This in addition to the reliability uncertainties could reduce the speed of implementation of these technologies.

4.2 Automation

4.2.1 Corporate social responsibility

"Corporate Social Responsibility is a management concept whereby companies integrate social and environmental concerns in their business operations and interactions with their stakeholders."

(United Nations Industrial Development Organization, u.d.)

Even though automation could yield great OPEX reductions, efficiency and safety increases for the firm, it can also have a negative effect on the surrounding communities and societies. Automation could eliminate job positions or even whole professions. PwC's study on the matter, estimates that automation could replace 30% of UK jobs, even worse so in the US with 38% (Berriman & Hawksworth, 2017). This is affecting O&G process across the supply chain, with manufacturing and transport & storage being some of the most endangered operations from the study. This can be a concern for the employees that have spent their whole life building a career around O&G operations, and will now have to find other career options. If unemployment rates increase because of automation, businesses would need to address this, and it could serve as a strategic business move for better public reputation. The PwC survey argues that other jobs and occupations will arise from the automation trend, but they also emphasize that most of these jobs will be for the highly educated.

4.2.2 Liability

Who is responsible the case of an accident involving automated machines or vehicles? Removing the human operator puts a higher liability on the end manufacturer and component manufacturer of the automatic machine and it will increase the overall complexity of the liability apportionment (distribution of responsibility). This could be a concern for the manufacturers of automatic machines or vehicles, and could potentially slow down the development progress. The concern is especially significant considering the risks associated with O&G products with the consequences of spills, leaks, explosions etc. (Manchisi & Goodwin, 2017).

4.3 Big data & IoT

4.3.1 Cyber security

Efficient use of IoT requires a network based framework in which all the IoT components can communicate. The more open these connections are, the faster they can communicate. Gaining access to one IoT node in the network could potentially give you control of and information on all of them, and if used by the wrong people with the wrong intentions, the damages can be significant. Gaining access to one IoT component could cause severe problems by itself, if the component is critical for the operations, as it may halt the entire production.

Here is a list of possible threats and vulnerabilities:

Threats & Vulnerabilities	
Counterfeiting	Malicious modifications
Denial of service	Password-based attacks
Eavesdropping	Man-in-the-middle attacks
Buffer overflow	Phishing

Figure 22: Cyber security threats and vulnerabilities (Deloitte)

These threats could cause some serious financial problems for an O&G company. A denial of service attack could potentially suspend production for days, with millions of dollars in lost revenue. The importance of security of a network increase with more IoT component, higher complexity of the IoT and more reliance on them.

Information collected for the big data analysis could potentially be corrupt or wrong resulting in false analysis of the situation. This incorrect information could lead to decisions making on the wrong basis, and cause costly unnecessary actions. Another issue could be someone intercepting the connection from big data, gather useful information in the form of eavesdropping. Such attacks could go undetectable until someone uses this information actively.

4.3.2 IoT investment balancing

Investment costs are also significant for IoT equipment. The more IoT you add, the higher the investment costs and handling complexity. Sensors in industries are in place to ensure availability of the machines, so adding more sensors should increase availability and decrease costs associated with the maintenance, downtimes and failures. This will need balancing to generate optimal investment returns. This graph is an illustration of this relationship.
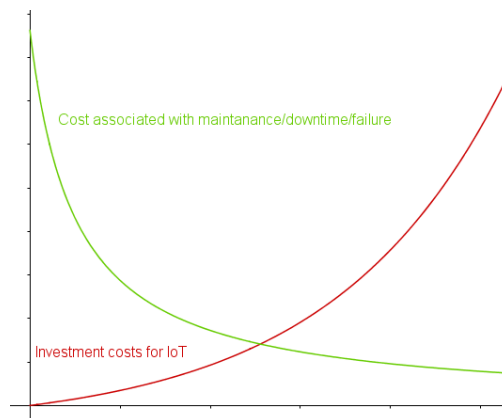

Figure 23: IoT investment balancing

This graph is only an illustration of a relationship, and will be different for each type of machine and sensor. The cost associated with maintenance/downtime/failure is the expected costs of the unavailability in machines. Its declining values represents declining probability of failure due to effective maintenance efforts. Availability of a machine or device will never reach 100% due to the imperfections and uncertainties in everything. Investing more into increasing availability will gradually yield lower returns. It is natural to assume that, the more precisely you want to measure a parameter, the more expensive the sensor is, and thus it has an exponential cost growth.

4.4 3D printing

4.4.1 Copyrights

Copyright laws are in place to secure the rights of the creator to distribute and use their products. The digital age have raised big concerns for illegal distribution of copyrighted materials, as they are reduced to files that can be distributed across the internet. If companies intend to use 3D printing for their spare parts management, they would have to get the rights for the specific parts. This could enable the spare parts market to shift from trading products to trading data (Geissbauer, Wunderlin, & Lehr, 2017). Furthermore, it is imperative that management fully understands these laws if they are planning to implement 3D printing, however the survey from Strategy& shows that the majority of the participants do not.

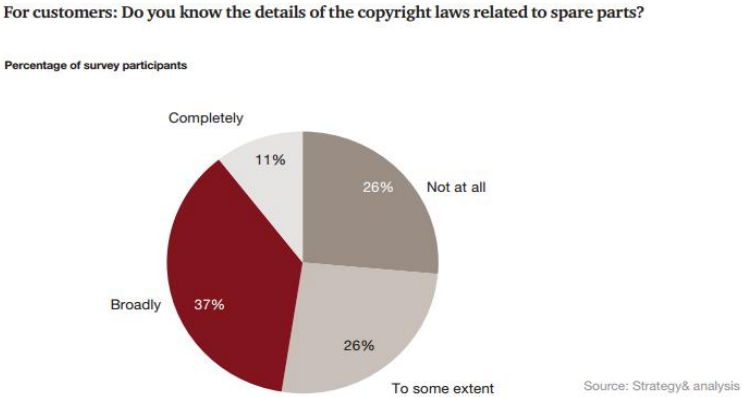*Figure 24: Survey on manager's understanding of copyright laws related to spare parts (Geissbauer, Wunderlin, & Lehr, 2017)*

This uncertainty could be due to the mainstream use of the technology being new, and the existing regulatory framework is not yet clear on the topic of intellectual property in regards to 3D printing (Malaty & Rostama, 2017). Wrong steps could result in costly lawsuits.

5 Conclusion

5.1 Automation

5.1.1 Automated drilling operations

Automatic drilling machinery could improve long-term costs, efficiency and safety in drilling operations. Since these are the main goals of these innovations, you could strongly argue for the implementation of these. However, there are strong drawbacks and limitations. The investment costs might be too high to be profitable. The theoretical OPEX gains from this innovation are not certain and it could carry hidden costs, like lack of reliability and lack of knowledge to utilize fully. I would expect some early adopters to test this technology and slowly implementing it completely. Based on these results, the market would decide to follow if successful or decline if not. I would assume this technology to reach the market before any of the other automation technologies in this thesis, due to the development of existing products, like the RDS equipment.

5.1.2 Autonomous underwater vehicles (AUV)

I-AUVs could yield great efficiency and cost gains. The ability to have an available robot to do tasks on its own initiative could serve as a great asset to upstream O&G. The technology at this point however is lacking, with the study showing that these are only capable of simple tasks. Further development costs on I-AUVs would have a significant impact on the product cost when they reach market. Therefore, I-AUV would need a long market maturity period for the price to be profitable in regards to return on investment. This innovation might require breakthroughs in robotics elsewhere to be developed. As it stands now, ROVs are well enough capable of doing the tasks currently required.

5.1.3 Autonomous transportation

Removing human error modes from transportation can be great for avoiding fatalities and spills. Autonomous roads are seen as a desirable future across industries, and many companies are showing interests in it. With O&G's high value cargo, it is obvious that can help deal with severe accidents and losses, concerning cost, safety and reputation. However, autonomous transport requires a complete overhaul of the transportation system to be effective, with every road user adopting automation. Otherwise, the human error factor is still present in traffic. This could potentially take decades. I would assume that automation of ships and trains is closer to implementation than trucks, due to lower complexity of the traffic system in which they operate.

5.2 Big data analytics in subsea production systems

I believe big data analytics will become a strong factor in subsea productions in the near future. Its ability to rapidly analyze and compare data from various sources, will contribute to improvements of some compatibility issues among suppliers of subsea equipment. This will enable the subsea O&G producers to increase flexibility in their selection of supplier, which will increase the overall performance of the system. The available knowledge of effective implementation and use of big data analytics might be lacking, but knowledge and information will increase as time goes and big data gains increased footing in industries. Other challenges such as cyber security would need additional costs and effort to combat, but is not a critical barrier to my understanding.

5.3 3D printing in O&G components production and On-site 3D printing

3D printing in development phases of products are already seeing great returns. I would expect this to continue and widen its market. However, the movement towards creating final and durable products will take some time and research to be fully adopted across industries. It is evident through the PwC survey that managers in manufacturing do not strongly believe in the short-term adaptation of final product 3D printing. Spare parts management through 3D printing would also take some time in order to ensure reliable parts, fast production and easy handling. However, the potential gains of lower downtimes and costs should be a strong incentive for investments into the development of such 3D printers. Issues surrounding copyright laws is avoidable through contracts with the copyright owners, or we may see changes to the regulatory system with 3D printing. I do not see this as a significant holdback for 3D printers in industries, as managers could easily learn and understand these laws if they decide to implement 3D printing.

5.4 IoT

5.4.1 Pipeline inspection and monitoring

There are great benefits from increasing connectivity and the number of parameters for pipeline monitoring. Due to the aging pipeline networks across the world, more maintenance are required, thus there is a need for effective maintenance planning. IoT will keep status updates of several parameters that can indicate errors or developing errors, and if handled correctly, can improve maintenance procedures in terms of cost and safety. However, increasing the number of parameters in a system could greatly increase complexity and cost to the point where it is unprofitable, and determining this threshold is essential for the value gains of the innovation. I expect pipeline and monitoring equipment to become gradually more complex, accurate and numerous. This development will follow the market maturity and decreasing price of monitoring equipment.

5.4.2 IoT as support

Machines, devices and equipment are becoming increasingly digital, and along with this digitalization arises opportunities and threats. For machines in O&G drilling, production and transport, the digitalization gives increase efficiency and safety, but also increased complexity and expertize requirements. IoT in the form of monitoring sensors is a great asset in all machines for its ability to observe performance parameters that leads maintenance decisions. Making digital machines networked will improve the ease of updates to software and could potentially increase performance. I expect this to grow naturally with the rate of digitalization, as it has within other industries, such as cars and mobile phones.

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