Universitetet
i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study programme/specialisation: Offshore Technology Industrial Asset Management	Spring semester, 2018, ~~Open~~/Restriced Access
Author: Robert Kallevåg Sele	………………………………………… (signature of author)
Programme coordinator/Supervisor: Prof. Jayantha Prasanna Liyanage External Supervisor: Torbjørn Wiig Petersen	
Title of master's thesis: Digitalization and Sensor Technology in an Industrial Context	
Credits: 30	
Keywords: • Digitalization • Sensor technology • IIoT • Digital Twins • Adaptive Strategy	Number of pages: 95 + supplemental material/other: 0 Stavanger, 15/06-2018

Acknowledgements

I wish to express my gratitude and thanks to Professor Jayantha Prasanna Liyanage for an excellent master program, and for choosing to be my supervisor on the master thesis. I´m grateful that you share your mind and vision during class, and for being straight, honest and pinpointing the important matters throughout our sessions.

I would also like to award a sincere thanks to my supervisor at Øglænd System, Torbjørn Wiig Petersen for sharing his thoughts on the subjects discussed, and for guiding me on the right path And also to Øglænd System for choosing me to work on this exciting subject.

I would also like to thank my informers in Statoil and Cognite for sharing their thoughts on digitalization and systems in the offshore O&G industry, in which gave valuable insight to the industry.

And finally I would like to award my family and especially my wife a big thanks, I truly appreciate the support I've had throughout these years as a student.

This thesis is the final result of 8 years at the University of Stavanger, and UIS has learned me to be curious, critical and dedicated in my projects and work, I am thankful for all the people, both students and lecturers I've met, who has formed my daily student life.

Abstract

The outlook for industry majors and minors are continuously changing, introduction of new technologies in the industry is shifting how product development, manufacturing, construction and collaboration is managed. The industry framework is innovating and the organizations within are starting to adapt new strategies for utilizing different technologies. Digitalization is multifaceted and can be utilized in many industry settings during the life cycle of an asset. The current trend is that the competitive advantage of successful adapters is outperforming lagging organizations, it is time to innovate.

Øglænd System is an global industry partner and provider of products and services for several industry areas, a long tradition with supplying the upstream O&G projects in Norway, and in recent years a global approach on delivering systems for the offshore industry worldwide has led to focusing this thesis on utilizing possibilities that lies in adapting to the developing industrial O&G digitalization process. This thesis is investigating the technologies that is transforming traditional industrial collaboration and competition with focus on sensor technology IIoT and smart products, these are often talked of as revolutionary technology that is going to transform the industry.

This thesis investigates how Øglænd System as an industry supplier can incorporate sensors on their product range Mekano® and adapt to target O&G industrial digitalization objectives.
In addition to incorporate sensors for delivering a new function, a finding was that this sensor network and the industrial eco system can be utilized for further product and service development with a smart connected product strategy. Using this strategy opens up for a new business model and creates a bonding between the use case and the development of products, but requires effort in creating new organizational functions that support this. The technical considerations are reviewed trough a digitalization architecture created for the industry 4.0 as a stepwise description of the findings and reviews in this thesis to develop this strategy into value.

Abbreviations and Acronyms	
AI	Artificial Intelligence
ADC	Analog to Digital Conversion
API	Application Programming Interface
AR	Augmented Reality
CAPEX	CAPital EXpenditure
CBM	Condition Based Maintenance
CCR	Central Control Room
CM	Condition Monitoring
CPS	Cyber Physical System
DAC	Digital to Analog Conversion
EDW	Enterprise Data Warehouse
EI&T	Electro, Instrumentation and Telecommunication
E&P	Exploration & Production
EPC	Engineering Procurement and Construction
ERP	Enterprise Resource Program
HSE	Health and Safety Executive
FFT	Fast Fourier Transform
HMI	Human Machine Interface
HVAC	Heat, Ventilation & Air Conditioning
ICT	Information & Communication Technology
IOC	International Oil Company
IIoT	Industrial Internet of Things
IoT	Internet of Things
IT	Information Technology
LCI	Life Cycle Information
LPWA	Low Power Wide Area Network
MMO	Maintenance and Modification Operation
NCS	Norwegian Continental Shelf
MEMS	Micro Electric Mechanical System
M2M	Man-to-Machine
NDT	Non Destructive Testing
NOK	Norwegian Kroners
OPEX	OPerational Expenditure
O&G	Oil & Gas
OT	Operational Technology
PLC	Programmable Logic Controller
PnID	Process and Instrumentation Diagram
R&D	Research and Development
RTD	Resistance Temperature Detector
RTU	Remote Terminal Unit
RAMI4.0	Reference Architecture Model Industrie 4.0
SCADA	Supervisory Control And Data acquisition
SIL	Safety Integrity Level
USD	United States Dollar
VR	Virtual Reality

Figure Index

Table Index

Index

Section 1: Introduction & Background

1.0 Introduction

Digitalization has been gaining momentum in developed industries the recent years, falling oil prices has refocused the O&G majors to take interest in this development, and challenges the industry to join. It has become a critical business need to digitalize, and is not just a buzzword anymore (Devold, 2017). It is seen as a necessary approach for becoming sustainable and competitive to other energy sources. So what is digitalization in this context?, Gartner defines digitalization as *"the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business"* (Gartner, 2018, p. 1).

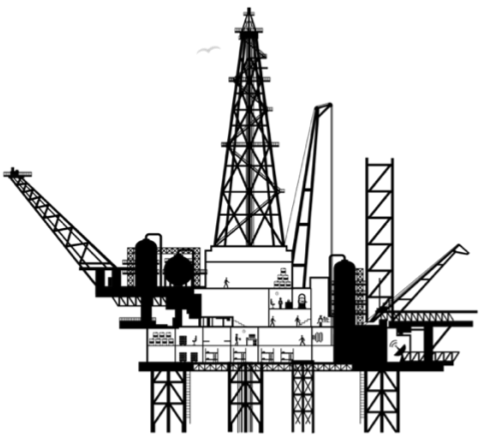


Figure 1: Offshore Topside (Bloomberg, 2018)

The framework for cooperation and solving the difficult challenges, are changing in the industry, the suppliers must adapt to this changing framework by integrating and support the new environment. Some organizations are striving to find their way, while others seem to adapt fairly quickly. McKinsey & Company has conducted research on digitalization in industry sectors across USA to find that only 18% of the digital potential is realized, and the gap is currently expanding between the adapters and the conservatives (Manyika, et al., 2015). Industry maturity is highly differentiated in the quest for digital use, knowledge intense sectors such as ICT, media and professional service are regarded as mature while a large portions of US sectors such as health care, education and manufacturing has a lower score on McKinsey´s survey on digital assets, usage and the employee usage of digital tools (Gandhi, et al., 2016).

The importance of keeping up with industry evolution is highlighted by (Gandhi, et al., 2016) backed with a survey from McKinsey & Company showing the industry leaders are accelerating and gaining increasing advantage over the competition, it seems to be the right time to start the digitalization journey. *"The digital age is seemingly moving faster than our previous industrial revolution did and could naturally create winners and losers."* (England, 2018, p. 6)

1.1 Background

Changes in the industrial framework is affecting every industry segment at this very moment. One key factor for these changes is the new digital revolution, often featured as industry 4.0. A frequent perception is that digitalization is leveraged by cheap sensors, maturing technology and computing power. Øglænd System, as a product developer, manufacturer and system provider seek to investigate the undiscovered possibilities and benefits sensor technology can bring to the industry and to their products. Digitalization in the industry has several similarities and objectives related to the asset management discipline, making the thesis topic relevant for this master program. Due to the high engagement and focus Øglænd has had, and still has in the offshore oil and gas industry, a natural delimitation is to focus the case study on this industrial context and explore the benefits and challenges that lie ahead.

1.2 Problem /Challenge

Øglænd System is digitalizing their product portfolio, services and project methods. However they are lacking the "new" smart connected products/IIoT products that are disrupting the industry environment today. The challenge in this thesis is to study technology trends and find a way to transform their flagship product range Mekano® to a smart product using state of the art sensor technology. The Purpose of this thesis is twofold, first it seeks to answer how Øglænd System can transform Mekano® to a smart asset that is targeting current digitalization objectives in the offshore O&G industry. Secondly, it investigates the creation of a digital strategy for utilizing the smart asset as a foundation for adapting a new business model and develop a smart connected product/system.

1.3 Scope & Objectives

The scope of this thesis is to review Digitalization in the context of industrial application with a focus on sensor technology, smart products and IoT. A case study on the upstream O&G is explored with respect to their strategies visions and objectives related to digital twins and the uses of sensors for condition monitoring an process optimization, which forms a further study of how Øglænd System and their relations to the findings in the case study of O&G can be coupled to form a basis for adapting to a changing O&G leveraging sensor data.
The thesis seeks to explore how to make the Mekano® a smart product using the case study and exploring strategies for creating smart connected products that deliver value for both customer and provider throughout its life cycle. This incorporates a review of technical aspects related to smart product composition and possibilities as well as strategic leverage of the new product attributes. The objective of the thesis is to highlight trends and important aspects of digitalization with respect to smart products and provide a strategy that elaborates important aspects and opportunities within a new eco system, while also meeting and adapting to the objectives of upstream O&G digitalization projects.

1.4 Research Method

The method used in this thesis was to first do a comprehensive literature review on the web articles, reports and research papers concerning the digitalization in the industry and present an overview of the technologies, business trends, strategies and methods.

The next step was to research established technologies such as sensor technology, communication technologies and contemporary uses of them through literature review on books and research articles. A digitalization conference was attended to gather information on vision, objectives and methods related to offshore O&G. The current information formed a foundation for having interviews with Equinor, Cognite and Øglænd System, which had the intention of understanding the digitalization process, challenges and technical information, as a basis for adaption and compliance in the strategy development.

The history, vision and product portfolio established by Øglænd System was studied trough published articles, conversations with employees, working with the products and trough the web page. The research on the organization was conducted to find the core functions that could be improved with smart sensors in the offshore environment.

1.5 Limitations

The thesis is limited to Øglænd System AS product, Mekano ® in the context of offshore O&G. From a life cycle perspective, the technical and challenging project execution and decommissioning phases in O&G projects should be accounted for in creating smart products, but the scope is to large and although it they were mentioned they were not accounted for in the main section. For the purpose of this report, the thesis is limited to explore technologies that is leveraging value of sensor data , as this is assessed to affect the digitalization strategy the most. The full range of technologies and their in-depth resolution is to vast to explore thoroughly in this thesis. Even though the thesis explores some in depth technologies for the smart connected products, containing sensor technologies, connection technologies and so forth, these are specific diciplines containing much more technical nuances than the author could explore and document in the timespan for the thesis.

1.6 Thesis Structure

Section 1: Defining the frame for the thesis and covers introduction, background for the thesis, the Challenge, scope objectives and methodology.

Section 2: Literature review on industry digitalization, seek to recap some of the important discoveries and invention that has formed the field of information technology and how it has scaled to become what it is. This section is also describing some of the digital trends with respect to digitalization, how these technologies are put together to form the new industry 4.0 concept and new technological solutions for the industry.

Section 3: State of the art, smart connected products, is reviewing how sensors are used together with digitalization technologies to form smart connected products, this section is also reviewing sensors technology, networks and batteries.

Section 4: Describes the contemporary state of O&G industry with its systems and arrangements offshore, this section describes the future outlook with digital twins and system integrations together with the objectives with this strategy. The objective for this section is to describe challenges and find problems to solve with sensors offshore for Adapting to the new strategy and solving the challenges

Section 5: Case study: Øglænd System on their background, function and current offerings to the industry and O&G industry. Mekano® support systems are evaluated with respect to function and challenges in the offshore topside system.

Section 6: Adaptive Digitalization Strategy with sensor technology is reviewing how Øglænd System can target "asset integrity" trough a condition monitoring sensor system, and how this system can be further used as a product development tool together with a new business model, value proposition and how to maintain the benefits.

Section 7: General Technical and human considerations related to the two aspects of the adaptive digitalization strategy, reviewed trough the 5C architecture

Section 8: Discussion is an overall reflection of the thesis project

The figure below shows an overview of the thesis sections.

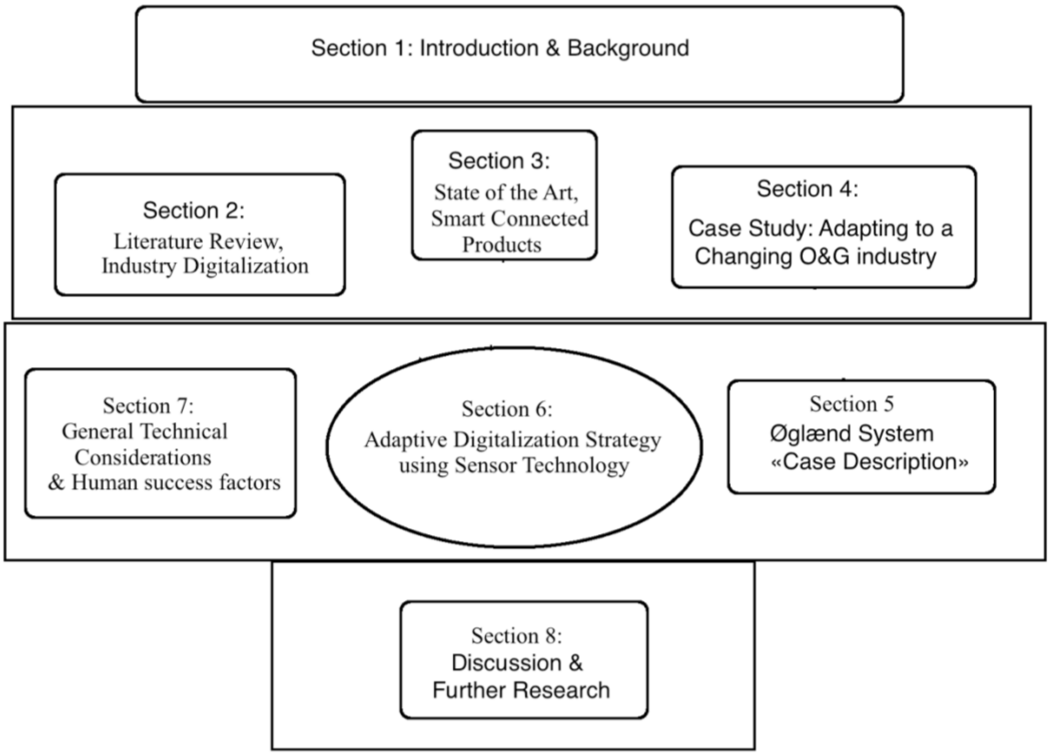


Figure 2: Thesis Roadmap

Section 2: Literature Review, Industry Digitalization

2.1 Background on the Digital Age

Information communication is of high importance for the development of all communication and computing technologies in use today. It started with the ability to count, and create systems for storing information in written form, it seems to originate about 3400 B.C. The Sumerians is thought to have invented the Arrhythmic math with use of tokens. "*Sumerians seem to have first developed cuneiform for the mundane purposes of keeping accounts and records of business transactions, but over time it blossomed into a full-fledged writing system used for everything from poetry and history to law codes and literature"* (Andrews, 2015, p. 6). The evolution of information storing has made it possible for mankind to build on what others have created, the importance of this structured method for information sharing practice cannot be overestimated, and lays much of the foundation for modern society.

From information storing to languages, the digital age relies on computers which use a different language than humans, this is called the binary language, and consists of using two digits, 1 and 0. This language "The binary Arithmetic" was invented by Gottfried Leibnitz (Rescher, 2013, p. 352). and was used in the construction of a proto enigma machine that can encrypt and decrypt messages. During the second world war, encrypted messages was an activator for creating a machine that could decipher them electro mechanically. This lead to the deployment of a highly secret project for developing the Bombe, which is built on the principles of the Touring machine. The development did go further to the development of one of the first digital computer, Colossus. (Cliomouse, 2018). From computers to Information Technology, the development of this field is by large related to Claude Shannon's work in the area of information, communication and systems, he is often referred to as the father of the information age. His most prominent work is the mathematical theory of communication. Which *"established the basic results of information theory in such a complete form that his framework and terminology are still used"* (Markovsky, 2018, p. 1). His thesis elaborates in particular how to address noise in a communication channel, and finds a quantitative method for measuring entropy in the information, which is explained as the measure of surprise in a "Bit" (Shannon, 1948). There has been many important contributions to information and communication technology development such as the "parity bit" by Richard Hamming, which is a method for reducing errors in communication. The development of the mathematical Boolean algebra by

George Boole, which is the basis for logic gates and modern practical applications for computers and more. Today digital technology has become a common good, prices are declining, computing hardware costs has decreased since the 1970´s, much due to the steady development of smaller building blocks in the modern classical computers, technically called semiconductors and circuits. The constant improvement in processing power and reduction in prices are often explained using Moore´s law which that is knowns as an *"industry synonym for continuous, periodic reduction in both size and cost for electronic circuit elements."* (Flamm, 2017, p. 1) The modern techniques for obtaining constant development and creating these small nanoscale structures for semiconductors today is called photolithography (Kuphaldt, 2009). The digital age is both utilizing the information technology systems as well as the operational technology systems (OT), the revolution of OT this started in 1969 with the introduction of the programmable logic controller (PLC) by Modicom , (Dunn, 2008) and is remaining today as the most common way of automating industrial processes. in IT advances in manufacturing techniques, such as computer aided manufacturing CAM, and Computer aided design CAD have been instrumental in optimizing the manufacturing processes (Klingenberg, 2017)

2.2 Technology Enabled Industrial Business Trends

Technology is a terminology used to describe techniques and processes to create a systematic functional product from base products. This is related to production methods, product composition, functionality and connections of products in a larger systems. Collins dictionary refers to *"Technology refers to methods, systems, and devices which are the result of scientific knowledge being used for practical purposes."* (Collins Dictionary, 2018, p. 1)

In the modern industry landscape, technology is transforming the way information is collected, shared, and used in the purpose of technological evolution. The digital technologies are increasingly forming the industrial environment with base technologies such as big data, cloud computing, data lakes, sensors, actuators, mobile technologies, network, storage and computing capabilities . (Chui, et al., 2013)

Figure 3: Base Technologies for IT business trends (Chui, et al., 2013, p. 11)

It is however not the technologies themselves that are transforming the business landscape, it's the creative ways its applied for creating new products, working smarter and collaborating easier, a strategy is needed (Deloitte, 2015). The technology enables industry organizations to work different from the traditional ways of gathering and sharing information, visualizing business ideas and creating value together. The combination of new technologies are powerful, and although technologies by themselves are interesting, it has a much more powerful effect when part of a transformation strategy (Westerman, 2017) The emerging trends in the industrial environment is related to the already mentioned and visualized six categories. However, since 2013, there has been breakthroughs and implementation of Artificial intelligence and the branch of machine learning, block chain technology is on the way in and cyber physical systems, digital twins and eco systems are characterizing the new environment. Emerging trends in the industrial environment is broken down to three sub categories by Gartner, (Cearley, 2016) which is thereby categorizing the functionality of the technologies. Intelligence consisting of the advanced algorithms, data analysis and research. The interfaces are characterizing human-technology interfaces such as digital twins and 3d models. And the last one, the mesh, which is the infrastructure of the technologies and the one that is enabling scaling, cooperation and sharing.

2.2.1 The Mesh

The mesh is defined by (Cearley, 2016) as a *"Dynamic connection of people, processes, things and services supporting the intelligent digital ecosystems".* (Cearley, 2016, p. 2)
The method for communicating with IT systems is changing from traditional coding by writing, to using the natural communication channels such as talking and showing. This revolution is leveraged by using smart algorithms for recognition of audio and video, and is being implemented in intelligent things such as drones and machines to control and command.
This ability is transforming the communication and collaboration between humans trough technology. The digital platforms that is in use today for handling information systems, customer experience, manufacturing systems, will be integrated to communicate with each other, and enabled by new data storing methods, new data platforms with Internet of Things (IoT) will be introduced in the IT systems (Cearley, 2016) Collaboration trough eco systems are becoming a new way of running and thriving business, the development is done through bonds and evolving together, when organizations and people do business in a eco system, they contribute to everyone involved. Create, scale and serve is leveraged by new technologies (Deloitte, 2018)

2.2.2 Digital Interfaces

The line between physical and digital is blurring, digital twins are using 3D Realtime dynamic software models of components and systems. "*Digital twin technologies are transforming operational efficiency in many sectors, and the traditional conservative process industries are beginning to adopt the latest digital thinking"* (Gartner, 2018, p. 3) Digital twin environments are being developed for many industries for the moment, Manufacturing and O&G industry is no exception. The digital twin is described as a "*Detailed reflection of the physical world and the digital world to appear as part of the physical world creating fertile ground for new business models and digitally enabled ecosystems"* (Cearley, 2016, p. 1). The digital twins are leveraging the benefits from Industrial IoT devices, contextualizing real-time data and information to be used by humans. (GE Digital, 2018) states that there is a significant difference between leveraging Industrial IOT, from consumer IOT, as they are much more complex in operations "*Monitoring a $10 million wind turbine is infinitely more complicated than tracking a person's footsteps, and the stakes are higher."* (GE Digital, 2018, p. 1)
The successful development and implementation of IIoT devices relies strongly on expertise on industrial environment and Operational Technology together with thorough knowledge and capabilities on sensors and software (GE Digital, 2018)
<In the Digital Twin environment visualization is a key attribute, and as Virtual Reality and Augmented Reality is becoming mainstream, the technologies are taken into use in the industrial environment as an effective Human / Digital Twin interface. Virtual Reality (VR) enables humans to become a part in the Digital Twin environment and Augmented Reality (AR) also known as HoloLens technology, puts the digital twin in the physical world by overlaying graphics in the current environment. Both these technologies are using the information delivered by digital twins as contextualized data from IOT devises trough 3D models and represents the real operations. Organizations are learning that the value of digital insight can bring positive synergies to operational processes, and as intelligent systems are now connecting the silos into a single source of truth less management is needed to cope with changes and changing things in engineering, procurement and contracting projects. Physical assets with digital twin environments will be complemented with real world elements, such as people, processes and places and "*the Internet Of Things will save consumers and businesses an Estimated 1$ Trillion a year in maintenance, service and consumables"* (Gartner, 2018, p. 12)

2.2.3 Intelligence Level

The intelligence level is leveraging machine learning capabilities through Artificial Intelligence (AI) and clever algorithms. AI will affect almost every technology enabled service using deep learning and neural networks that enables systems to adapt into the situation and can predict future events. (Cearley, 2016). In digital twins, AI is playing a prominent role in simulating processes and optimizing system. (Øyvann, 2018) however, the intelligence level is also comprising of intelligent apps which has the capability of organizing and prioritizing tasks, give advices and more "*By 2018, Gartner expects most of the world's largest 200 companies to exploit intelligent apps and utilize the full toolkit of big data and analytics tools to refine their offers and improve customer experience."* (Cearley, 2016, p. 1).

While intelligent software performs tasks that improves business by improving capabilities, Intelligent things are improving monitoring, control and task performance, intelligent things use the base technologies of sensors and actuators, big data, and mobile technology together with AI and algorithms. Gartner structures them into Robotics, Drones and Autonomous vehicles, but Internet Of Things (IoT) devises are also present here. IoT business trends are changing the data collection methods, making corrections, updates and services easier to manage and control. Closed Loop Decision making and real time monitoring are some of the benefits with IOT and Big data analytics (Chui, et al., 2013). IoT devices and analytics are used to understand the "use case" of products and services better with processing capability and advanced analytics that far exceeds human capacity, AI can gain insight from seemingly unstructured data. *"Leading companies are embracing AI to perform repeatable, redundant tasks and to process large amounts of data not to avoid human interaction, but to enrich it"* (Altman, 2017, p. 1). When the amount of connected intelligent devices are becoming large enough, new possibilities arises. "*As intelligent things evolve and become more popular, they will shift from a stand-alone to a collaborative model in which intelligent things communicate with one another and act in concert to accomplish tasks"* (Cearley, 2016, p. 1).

In general, the technology enabled business trends are leveraging the ability to cooperate trough connectivity, adaption and integration for scalability, new collaboration methods and by enabling new business models and development.

2.3 Industry 4.0 the Future Industry Environment

The future industry environment is envisioned to be driven by industrial decentralization of smart industrial products (IoT), that is composed in a wireless network which facilitate communication and control of the processes in manufacturing (GTAI, 2018). Technological solutions on intelligence and visualization are integrating to form the vision for a future industry (Schwab, 2018). Industry 4.0 and Smart factory is often interchanged, and these are related to the German vision for future manufacturing that was introduced in 2011 on the Hannover messe trade fair, "Industrie 4.0" (DLG-Expert report 5/2015, 2015) Industry 4.0 / Smart factory is according to (Lasi, et al., 2014) described as "merging of physical and digital" trough the Cyber Physical Systems (CPS), these systems that are controlling the industrial processes, products and systems connected with the digital representation, aligning with (I-Scoop, 2016) description of this system.

Self-organization of production processes are becoming more frequent as the traditional production hierarchy is decentralizing into component level, and new systems are emerging for distribution, procurement and communication, the systems are thought to be more human centered in the future. However clear definition is difficult to establish, as the terminology is a still a vision for the future state of manufacturing. (Lasi, et al., 2014, p. 240).

The grand vision of industry 4.0 is to optimize processes and to make production flexible and agile, creating a framework for faster adaption to market needs. Mc Kinsey and Company defines Industry 4.0 as *"the next phase in the digitization of the manufacturing sector, driven by four disruptions Big Data, Advanced Analytics, Human Machine Interface and Digital to physical transfer."* (Baur & Wee, 2015, p. 1).I-Scoop highlights that industries together with a new connectivity between all the processes and people and IoT enabled industrial assets will drive innovation and collaboration in facilitated eco systems (I-Scoop, 2016).

2.3.1 Reference Architecture Model Industrie 4.0

The Industry 4.0 Concept is made possible by standardizing the digital architecture, which makes it possible for architects and engineers to communicate. The RAMI 4.0 architecture facilitates horizontal and vertical system integration, life cycle tracking and connection of Cyber Physical Production systems (CPPS) this helps giving consistency across the entire value chain (I-Scoop, 2016). This is the system integration architecture, that integrates the cyber physical systems. (Platform industrie 4.0, 2016) is the platform that combines all the processes within industry 4.0 to form a modern flexible and decentralized factory.

2.3.2 Cyber Physical Systems

The cyber physical systems are connected to the operations of a plant, and can be seen as a combination of Information Technology (IT) and Operational Technology (OT). It is based on the latest control systems (I-Scoop, 2016). This type of system is the base technology for connecting IOT devices with sensors and actuators for monitoring and diagnosis, tracking, controlling and control processes. *Cyber-physical systems essentially enable us to make industrial systems capable to communicate and network them, which then adds to existing manufacturing possibilities.* (I-Scoop, 2016, p. 22).

An architecture for the industry 4.0 concept has been developed by (Lee, et al., 2014, p. 18) which explains step by step how to develop and deploy a cyber physical system for a general manufacturing application. Which is elaborating how sensors, actuators and communication is facilitating each stage towards an industry 4.0 concept with optimized, self-adjusting and configurating manufacturing process. The use of Cyber physical systems are the emerging method for controlling and maintaining assets in the industry, and functions as a facilitator for system of systems *"Cyber-Physical Systems (CPS) is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities"* (Lee, et al., 2014, p. 18) both smart factories, agriculture, O&G, shipping and renewable energies are some of the industries currently looking into the construction of digital twins and managing them through cyber physical systems.

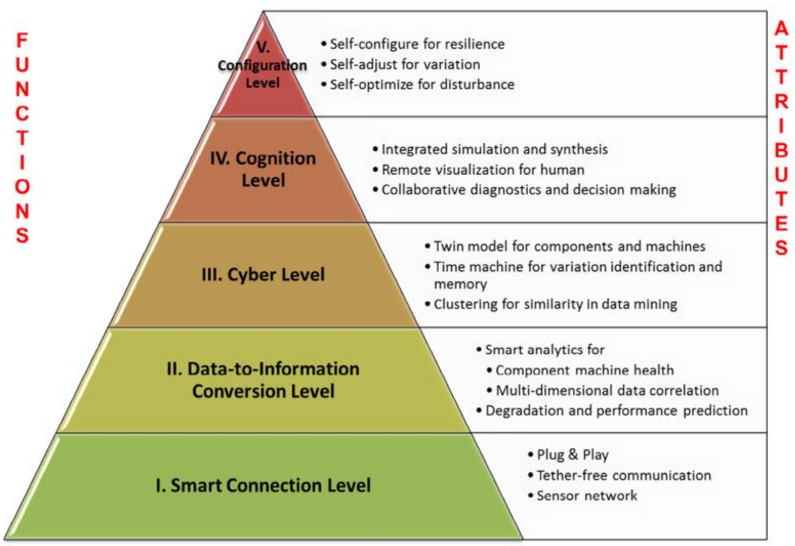


Figure 4: 5C architecture for implementation of Cyber-Physical Systems (Lee, et al., 2014, p. 19)

The main functions of CPS is to retrieve real time sensor data and information from cyber systems such as Enterprise Resource Program (ERP) systems and the second feature is to analyze big data and take use of smart analytics, a step by step 5C architecture is proposed by Today's factory attributes search to optimize Precision, Producibility & Performance, trough technologies such as smart sensors with fault detection, condition based monitoring, diagnosis and lean operations. The future industry 4.0 is however leveraging these attributes and AI for self-configuring, self-adjusting and self-optimizing. (Lee, et al., 2014)

2.3.3 Industry 4.0 Technologies

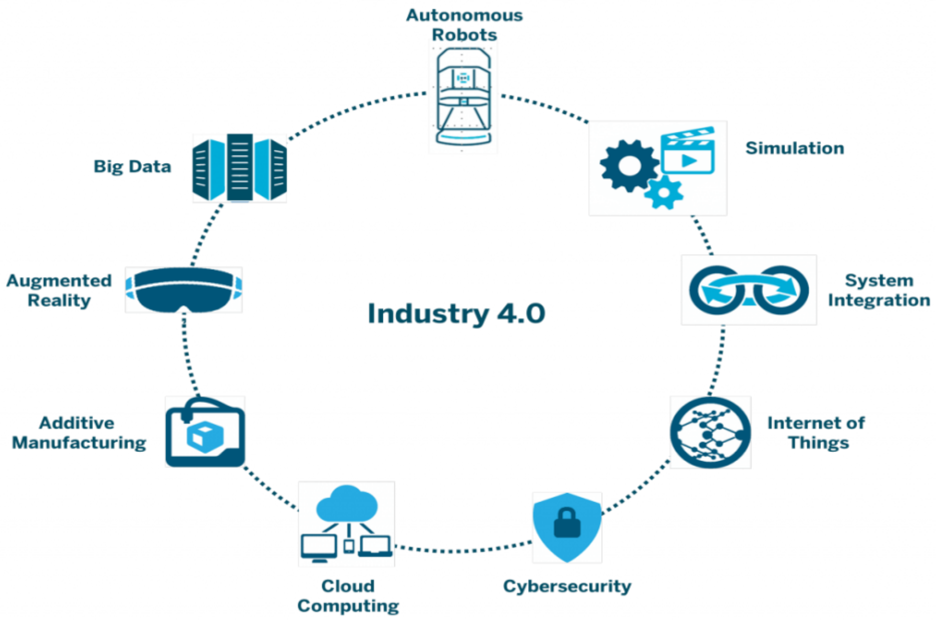


Figure 5: Industry 4.0 technologies the Nine pillars, (Melanson, 2015) (Rüßmann, et al., 2015)

The technologies that supports and facilitates the industry 4.0 development are visually represented in

Figure 5, Although industry 4.0 is a vision for the future, all of these technologies are developed and in used today. The existing technologies are being integrated to streamline and automate previous fragmented and manual workflow *(Melanson, 2015)*. In addition to these nine technologies, mobile devices, smart connected products, smart sensors and artificial intelligence is also inflicting the industry environment today.

2.4 New Technological Solutions

The new technological solutions are consisting of the nine industry pillars but is also leveraging the current industrial business trends, such as Intelligence, Interfaces and mesh.

2.4.1 IoT

The Internet of things is described a network of smart connected devices that communicates Seamless trough internet (Alsen, et al., 2017, p. 2). And consist of products which is not traditionally connected to internet, such as regular household items and other monitors with sensors (Meola, 2016). The number of IoT devices are increasing at an accelerating pace and by now the number of connected devices have surpassed the number of living people on the planet (PTC, 2018) It´s estimated that by the end of this decade, there will be approximately 50 billion IoT connected products. The estimated value of this segment is predicted by McKinsey's Global Institute to have an economic impact between 4 and 11 trillion USD by 2025. (Mc Kinsey & Company, u.d.)

IoT devices ranges from locking mechanisms on doors, to refrigerators that is smart and connected to the internet. IoT devices communicate through wireless technology, leveraging different bandwidths, protocols and information transferring practices, since the field of wireless transfer of data is a relative new field, and especially for sending sensor data, there is still much innovation and research on connection and data transfer, in the near future this will likely balance to a standard. (Alsen, et al., 2017) *"By 2022, we expect that most IoT applications will use LPWA networks, which will make connectivity choices less confusing. (5G will still not be widely available at that point)."* (Alsen, et al., 2017, p. 3)

2.4.2 Big Data

Data has traditionally been processed in silo based data architecture, with structured data for analysis internally within a company, (Aggarwal, 2016) for the purpose of processing orders, managing industrial processes for leveraging sales. Big data differs from the traditional use of data by combining more sources and more volume for analysis and pattern recognition, these sources are often a combination of unstructured raw data, from for example sensors, together

with more structured data from information systems such as Enterprise Resource Program Systems (ERP).
Originally, big data was characterized by three V´s, where “Volume” is representing the amount of data that is constantly growing, “Variety”, for the different formats and “Velocity”, for how quickly the data is generated and analyzed (Berman, 2013, p. xx). In recent years another V has arrived and is a measure of how trustworthy the information source is “Veracity” (Sherif, 2017). In the nine pillars of industrial advancement, both big data and system integration is used to leverage the new industry concept, analytics take advantage of connected systems as more connected data bases are, the easier it is to extract and compose new analyses.
The term big data is different from small data and “*Big data, refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze.”* (Manyika, et al., 2011, p. 1).

Big data has value in the industrial environment due to the possibility to predict causalities that can reduce downtime, optimize asset performance and reduce maintenance costs through application of advanced analytics and machine learning algorithms (GE Digital, 2018, p. 1).
Big data can be analyzed with different techniques such as AI and clustering to analyze the divergence of data clusters (Anderson, et al., 2017), but the general approach is to deduce big data to more structured and informational data sets (Berman, 2013, p. xxiv). *“Big Data analysis is a multistep process whereby data is extracted, filtered, and transformed, with analysis often proceeding in a piecemeal, sometimes recursive, fashion”* (Berman, 2013, p. xx).

Artificial Intelligence is often mentioned in the context of Big data, and this is due to the computing capability and also the ability to use big data as, learning data for machine learning. Introduction of real time targeting and AI is giving instant accessibility to data analytics on the fly (matthews, 2017) From an organizational perspective, the storing method integration and connectivity are essential in leveraging big data. the introduction of Industrial IoT devices and unstructured data poses a challenge for the big data analytics due to the different formats on sensor reading that can be temperature, location or contextualized information such as sales historic (Porter & Heppelmann, 2015 a, p. 7) which needs a different approach on data management.

2.4.3 Edge, Cloud, Data Lake & Analysis

The cloud, data lakes and Edge computing are technologies that facilitates IoT devices and while the "Edge Computing" isn´t a new thing, it´s increasingly getting more popular.
Edge computing is essentially processing of information directly in the smart product and is the technology that facilitates a decentralized method for processing data. In the IIoT context, edge computing allows for rapid response (low latency) to the process the device is connected to, and also reduces the amount of data that is necessary to communicate through the wireless internet, giving rise for narrow bandwidth networks and far out placement of devices such as in mines, and on offshore rigs. *"'edge' refers to the computing infrastructure that exists close to the sources of data, for example, industrial machines (e.g. wind turbine, magnetic resonance (MR) scanner, undersea blowout preventers), industrial controllers such as SCADA systems, and time series databases aggregating data from a variety of equipment and sensors."* (GE Digital, 2018, p. 1)

The combination of edge and cloud has positive synergies on low data transport in regular operations, and high processing capabilities when analytics is needed. The cloud has scalable processing capabilities, has ability to connect to other information sources and is not power sensitive the same way an IoT device is. Companies that offer cloud solutions are generally called cloud providers, and some of the most popular is Microsoft, with the Azure platform, followed by Amazon, IBM, Salesforce and SAP (Evans, 2017). *"with the cloud, users can access IT resources at any time and from multiple locations, track their usage levels, and scale up their IT capacity as needed without large upfront investments in software or hardware."* (Nichols & Sprague, 2011, p. 50).

The cloud is built up as a service, choosing the right one for the company is important, the services are differing on the amount of integration and dependency.

- Infrastructure as a Service (IaaS) is the provider of storage, and network. Meaning the organization/user manages operating systems applications and programming framework (Nichols & Sprague, 2011)

- Platform as a Service PaaS enables users within the organization to deploy developed applications on the platform (Nichols & Sprague, 2011)

- Software as a Service (SaaS) enables users to access applications that is deployed and run them on the cloud infrastructure (Nichols & Sprague, 2011) Running software in the cloud, making the application available everywhere and data is stored in the cloud (IBM, 2018)

The clouds can be composed of communities that is sharing the same information, called community clouds which means that two or more organizations are collaborating.
The different service levels have positive such as data processing capabilities and storing and availability, the flip side is less control over data, location and confidentiality.

Data management can be a challenging task when collecting data from multiple sources a, The Data Lake is a method for storing data that facilitates a flexible computing architecture, where data is stored at the same location but with different structures and formats and different information values (Amazon, 2018). The data lake is a concept that have been developed in the aftermath of big data to facilitate storage of unstructured data, together with semi structured data, format and structured data (Khine & Wang, 2018) (Ronk, 2014)

The data lake gives the whole organization ability to analyze data in the lake to leverage business intelligence. An organization can store all its information in a data lake and use these tools to facilitate machine learning and visualization of data for deeper, business, customer and partner insight (Porter & Heppelmann, 2015 a).

2.4.4 Digital Twin, System Integration, Simulation and AI

The concept of a digital twin has been around for some years, but it is the emergence of IoT products that has made it imperative to use in today's industry (Marr, 2017) It is a virtual representation of the ecosystem containing IoT devices that is operational in an industrial asset throughout its lifecycle. The modern digital twin can consist of products with a virtual representation or the combination of many products in an industrial asset such as an airplane, oilrig, or an industrial manufacturing plant. (I-Scoop, 2018 b), The digital twin is used in design, construction and operational phase to integrate engineering, 3D models and software together with sensors and actuators in the model (Gartner, 2018). The digital twin is overlaying the cyber physical system, and is composed in a human oriented way, enabling analytics, control and communication, and also providing a visual on the condition.

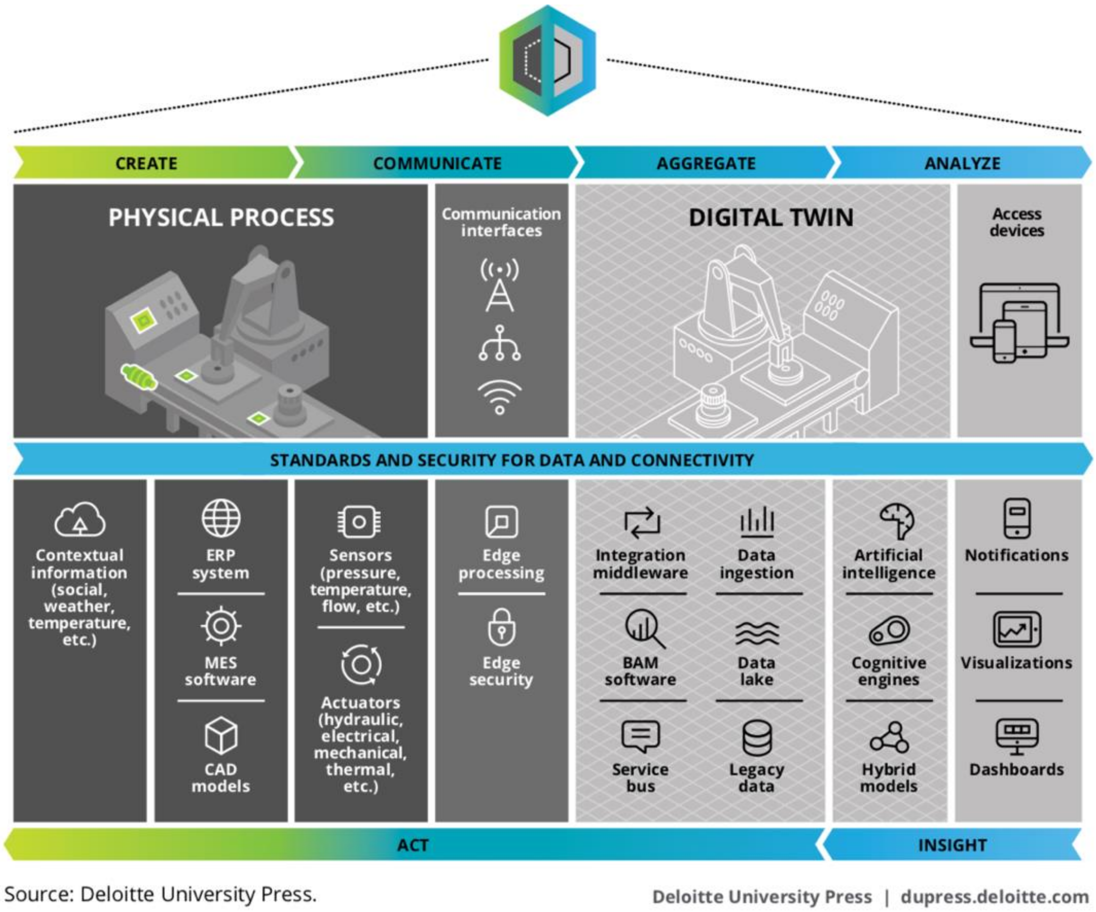


Figure 6: Digital Twin Conceptual Architecture (Deloitte, 2017, p. 8)

Deloitte´s digital twin conceptual architecture shows the process from the asset and twin is created. The physical system is fitted with sensors which are accurately placed and replicated in the twin, these transfer data trough communication channels utilizing edge processing for local analysis before its aggregated to the cloud and into the digital twin for analysis. From there, data scientists can process the information and return it for adjustments giving a closed loop connectivity (Deloitte, 2017).

The twin model utilizes what (Rüßmann, et al., 2015) was predicting in 2015, the best from both worlds, traditional simulation of products and processes together with real time data which mirrors the physical asset(s) in the digital world. This system utilizes real time data of an updated and reliable single source of truth, the composition and the coherent updated information is effectively utilizing engineering data and translating it into business value by having foresight of potential mechanical failures which can be mitigate, and driving process optimization throughout the assets life cycle (Gartner, 2018). For a digital twin concept to be scalable and live, system integration is essential, an comprises of both the collaborative part, between companies that are partnering and working together on the same targets. But also the horizontal and vertical integration of organizational systems and processes, system integration is an important aspect in using digital environments. *“Most of today’s IT systems are not fully integrated. Companies, suppliers, and customers are rarely closely linked. Nor are departments such as engineering, production, and service.“* (Rüßmann, et al., 2015, p. 5)

The future industry landscape will get benefits from interconnected systems and workflows, RAMI 4.0 architecture from Germany, and the Industrial Internet Reference Architecture (IIRA) from the Internet Consortium are developing a framework for connecting these cyber physical systems consisting of sensors and actuators with the other systems such as Enterprise Resource Planning (ERP) for vertical (hierarchical) integration, and the integration and life cycle management, with processes, IT and suppliers in a horizontal integration. Effectively providing an architecture for decentralized interconnected digital system (I-Scoop, 2016).

This ubiquitous connectivity facilitates the use of intelligent software for interconnectivity between human and digital environment, Virtual Reality (VR) is a technology that is mimicking the reality with a screen overlay and is adopted to be used as a training device for different purposes. And is amongst others used by NASA, which is one of the early adopters that is training astronauts with this technology (Goeden, 2017). One of the big potential use cases on Human Digital Interface comes with Augmented Reality (AR) also known as HoloLens technology, which is quite similar to VR, but is overlaying graphics in the visual field of a person, and can thereby create holograms in the physical room they are standing in. This technology is used for collaboration between people and complex 3d models structures or just delivering pure information such as data logs right in the visual field of the worker (AVEVA Group, 2018)

2.4.5 Cybersecurity

In the past, O&G has run OT systems that have no connection with the internet, but new models for efficiency and decision making requires the connection between IT and OT (Ernst & Young, 2017). A new context on industrial application of sensor technology and digitalization induces concerns on cybersecurity, which is related to both the operating system and the connected devises, which in context of critical operations in the industry can have large consequences.
"With the advent of smart, connected devices, the game changes dramatically. The job of ensuring IT security now cuts across all functions." (Porter & Heppelmann, 2015 b).
The vast amount, and expected growth of IOT devices poses as a serious risk for attacks trough hacking of the devices in the industry due to lacking focus on the weaknesses on the operating systems that run IoT devices (Ernst & Young, 2017). Industrial IoT devices are evaluated to be more secure than consumer products, due to a higher focus on this aspect, and if often operating in an environment protected by rigorous firewalls, there are however often weaknesses in merging of old industrial control systems and new IoT products due to mismatch on security features related to software (McKeon, 2018).

Some of the risks that are induced comes from outdated OT software and together with more sophisticated methods for imposing on the industrial network (McAllister, 2017).New technologies like Block Chain are although envisioned to play a role in the securing of IoT products and the connected network related to the attributes of the technology (Reinecke & Gibson, 2018). The technology is based on a decentralized method of storing data, and is using technology in a chain of information that is being validated by the network, creating high integrity by verification (matthews, 2017).

2.5 Smart Assets

Smart assets are made possible by using sensors, algorithms and connectivity, however, the components themselves does not have to be smart, but the combined system must be capable of using data to create synergy for the users (Bughin, et al., 2010). Smart assets can provide useful data for decisions that are being made, either by the owner of the system, or the user of the system. For example, the use of wired sensor networks has been deployed in the city of Stockholm, Singapore and London to monitor traffic and optimize rout planning and minimize congestion, and also applications such as using sensors in water transport and distribution gives the ability to monitor the system, and act on diverging performance. (Bughin, et al., 2010).
Smart Assets are defined J.Raza and J.P Liyanage as "*Those production assets that actively exploit digital capabilities and digital infrastructure smartly and strategically in conjunction with the extended data-knowledge-experience sharing enterprise setting, creating a highly interactive hybrid techno-organizational environment.*" (Raza & Liyanage, 2007, p. 2509)

In the industrial context, the objective of the system must be priority number one, and also maintaining industrial integrity throughout the assets life cycle. (Raza & Liyanage, 2007, pp. 2514-2515) created an analytical framework for the achieving technical integrity for offshore production facilities, which reviews critical incidents that lead to production loss and combines business intelligence (historical and organizational data) and performance cues (experience and knowledge) to a database with contextualized data for analytics.The combination can be utilized to form risk based decisions and create logic trees for mapping of the risk factors. The use of this framework can identify loop holes that can be solved with smart technologies. *"The concept of smart assets focuses heavily on the cost effective use of resources, competence and data demands an integration of multi-disciplined teams for technical integrity and performance optimization"* (Raza & Liyanage, 2007, p. 2509) The introduction of higher processing capabilities with edge and cloud solutions, better connectivity and general development of Industrial IOT, and smart connected products are changing the industry. Deployment of smart connected product can leverage as smart assets in the industry.

Section 3: State of the Art, Smart Connected Products

3.1 Smart Connected products & System of systems

The new methods for cooperation and development trough networks of organic systems is characterizing the industrial collaboration trends. As eco systems of people and processes connect, so does IOT and the benefits from these products. Smart connected products does however differ from IOT products and is the bringing new capabilities to the industry environment. "*What is different with smart, connected products is that the products themselves are enabling the revolution. Their capabilities are unlocking new value and transforming both companies and competition"* (Porter & Heppelmann, 2015 b, p. 2).

In HBR on smart connected products, Michael Porter and James Heppelmann discusses the impact smart connected products have on the industry, it reshapes the companies and their development processes and facilitates new business models for the products. Due to the increase and interest of these products, they are increasingly embedded deeper in, and in, and trough broader systems. Smart connected products are transforming the manufacturing industry to take action and become IT hardware and software developers, and often leads to collaboration with organizations that develops software and hardware technology (Porter & Heppelmann, 2015 b).

The smart connected product has three attributes, consisting of the physical attribute, meaning the product itself with mechanical and electrical parts. The smart attribute that is composed of sensors, microprocessors, software and storage, that enables programming of functions for analytics, adjustments and visualization trough user interfaces and application interfaces. The third and final attribute is connectivity to cloud networks and applications, which can be enabled with wireless technology, or cables.
Components of smart connected systems are made with more processing power, better software and smaller packages for every year. (Porter & Heppelmann, 2015 b).
The smart connected future is redefining the industries from being product oriented to function centric, a part of the bigger picture , Smart Connected technologies opens up for new products and services and also functions as an incubator for new innovations. (Ostrower, 2018)
"Smart Connected Products will enable real-time visibility and analytics of actual product performance" (Littlefield, 2016, p. 1).

As reviewed in big data, IOT devices and data management systems in technological solutions, the transformation from a product to a smart connected product requires a new infrastructure on data management and sharing. Smart connected products require a new infrastructure for supporting the new attributes trough a software and management system connecting ERP systems and external information sources which is facilitated with cloud solutions. The smart connected products are opening the possibilities to create, join and evolve systems of systems, which is also spoken of as eco systems. The evolution of smart connected products is described trough five steps by Parametric Technology Corporation (PTC). (PTC Inc., 2014)

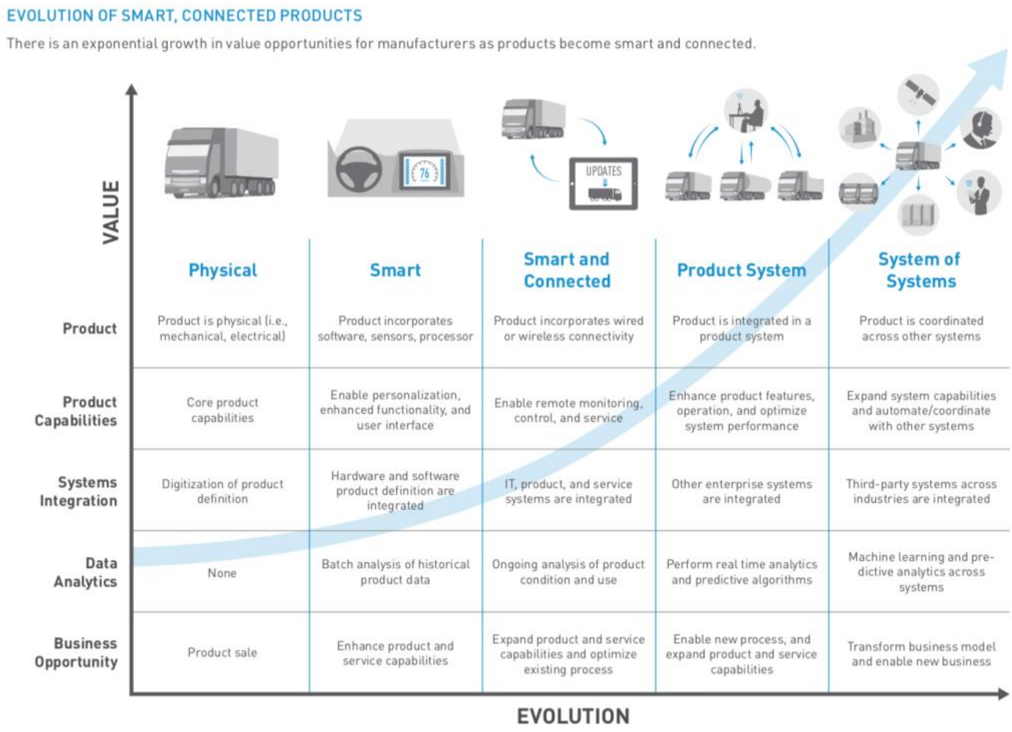


Figure 7: Smart Connected Products Evolution (PTC Inc., 2014, p. 5)

From a standard as is product to a smart connected product requires a strategy for how to contribute in the product system and system of systems. Smart connected product are equipped with sensors and processing capabilities. The capabilities of smart connected products then becomes to monitor, control, optimize and automate processes related to the product. A major milestone for these type of products, are that for the first time, data related to actual use is available for the product supplier, addressing the challenge with product feedback (PTC Inc., 2014). With this new capability the opportunity for new strategies emerge, the product can now be offered as a service and maintaining control over its performance throughout the lifecycle.

"By listening to the product during each and every stage of its lifecycle, you can access the information you need to transform how you create, operate, and service smart, connected products." (PTC Inc., 2014, p. 7)

3.1.1 Digital and Organizational Infrastructure changes

By looking at the product evolution, it´s clear that the capabilities are changing how the products can be utilized during the evolution. Each step requires the digital infrastructure is supporting the evolution. *"Smart, connected products require a fundamental rethinking of design. At the most basic level, product development shifts from largely mechanical engineering to true interdisciplinary systems engineering"* (Porter & Heppelmann, 2015 a, p. 9) . Developing a smart connected product requires imagination on how to adapt to the system of systems. However, a changed product development process also requires collaboration between silos in the organizational infrastructure that have traditionally been concerned with fairly different objectives and functions. As product development is one key change, so is the data centric method for leveraging this method, and having customer facing personnel that takes care of the Product as a Service business model. The new organizational functions that is proposed by (Porter & Heppelmann, 2015 a) is shown in figure 6.

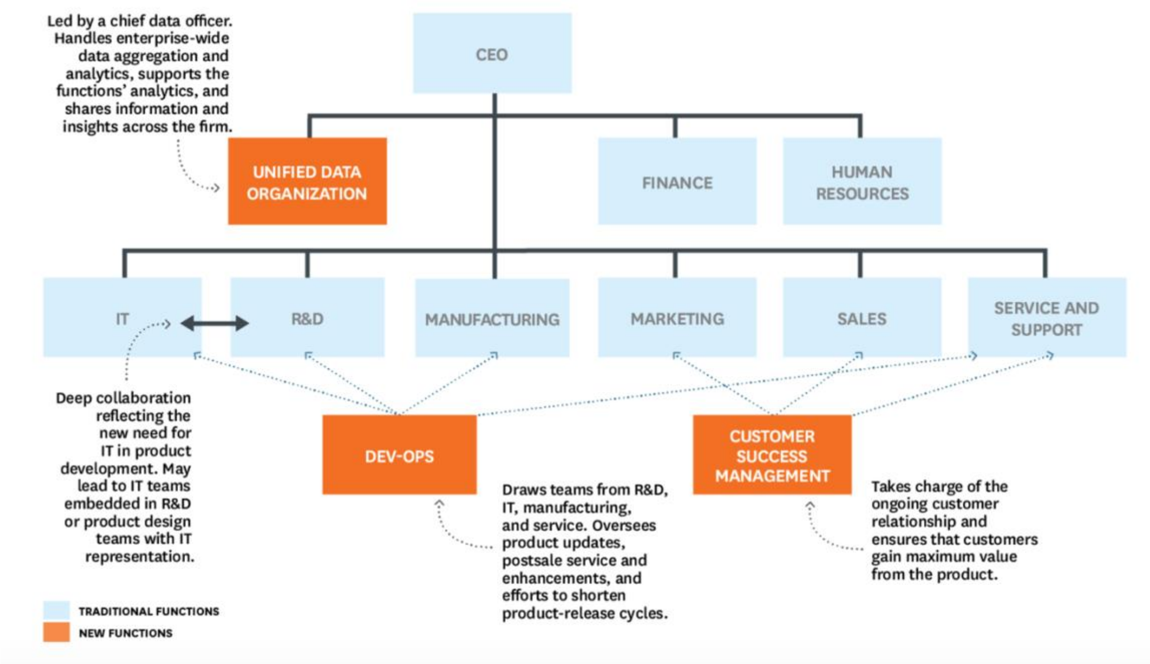


Figure 8: Organizational Structure new functions (Porter & Heppelmann, 2015 a, p. 27)

A new unified Data organizational function is proposed for the purpose of analytics and data management, this group is responsible for getting the most out of new data resources with collection, aggregation and the analysis of these. Because of the sheer volume and speed of data, the dedicated team will be responsible for all organizational functions and the respective data sharing. (Porter & Heppelmann, 2015 a)

Dev-Ops is the new branch of software and product development team that makes sure the product is optimized with respect to function and capabilities. Since the entire technology stack is related to hardware and software, the proper skillset and integration between IT and OT , design and development is to be set by this group of people. a smart connected product can be reckoned as a "evergreen" product, where software updates are providing a "as new" product with new or improved functionality. (Porter & Heppelmann, 2015 a)

The customer Success management is an important aspect of the "Product as a Service" new business case and has the responsibility for customer contact during the products lifecycle, ensuring proper functionality of the product.The development of smart connected products enables for further differentiation, and *"manufacturers must make critical strategic choices, and enable the right capabilities to create real value for their customers and differentiate themselves from competitors."* (PTC Inc., 2014, p. 8)

3.2 Data Management

In relations to the unified data management function, data management is the management of information with varying contextualization's. data management can be defined as *"an administrative process that includes acquiring, validating, storing, protecting, and processing required data to ensure the accessibility, reliability, and timeliness of the data for its users"* (Galetto, 2018, p. 1) Data management is not a new thing in the corporate world. Much of the current use is for keeping track of memory related to different processes in, say a manufacturing business. The data management is also used for all the different silos in the organization related to Development, Marketing, Sales, Economy and IT, that utilize data for their specific purpose. The new smart connected products, and IOT devices requires a different approach to data storing and retrieving these data, which is elaborated in the next sub section.

3.2.1 Data Lake & Database Management System

As technology that leverage large amounts of data is integrated, and the solutions for analyzing and benefitting from them are reaching the market, a silo based information storage system is not easy to extract information from. The data lake concept is created for this type of storing and extraction. (Porter & Heppelmann, 2015 a)

"These storage platforms are designed to hold, process, and analyze structured and unstructured data.1 They are typically used in conjunction with traditional enterprise data warehouses (EDWs)" (Hagstroem, et al., 2017, p. 2) the data lake enables big data analytics.

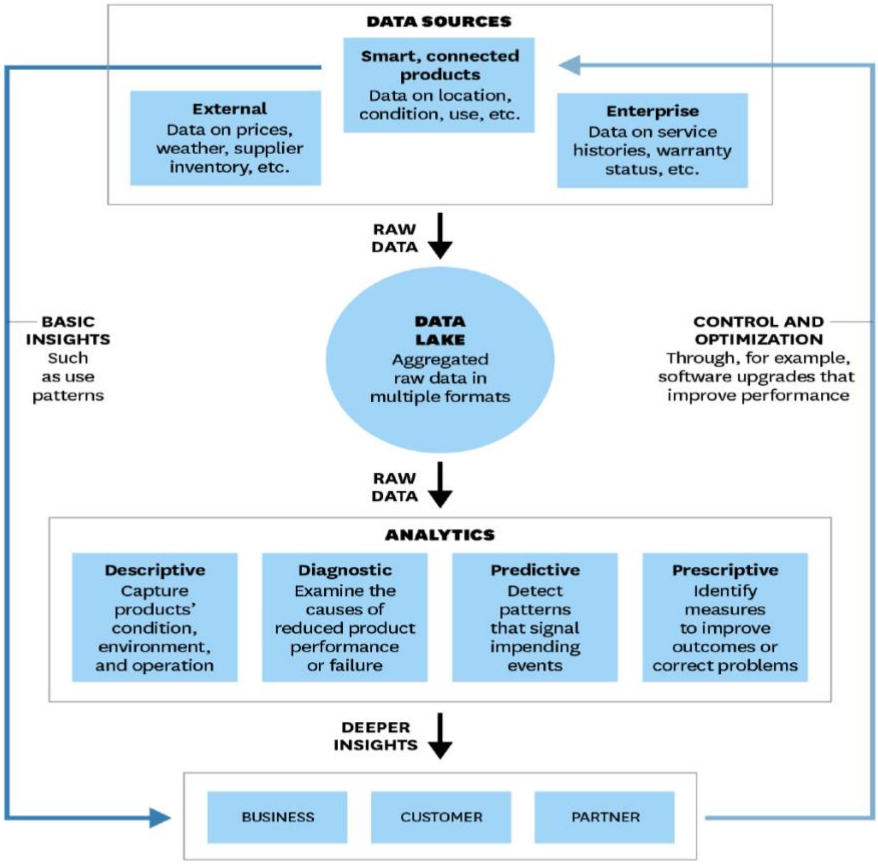


Figure 9: Creating Value with Data (Porter & Heppelmann, 2015 a, p. 8)

Figure 7 from (Porter & Heppelmann, 2015 a, p. 8), is illustrating the data sources and the storage method, data Lake, which facilitates the use of analytics on raw data, both structured and unstructured and in different formats. According to (Hagstroem, et al., 2017), the data lake is a pool of information, and the implementation of data Lakes can be done in a stage wise approach with different capabilities of collection and analyzing. The purpose is to enable big data analytics and also the Artificial Intelligence with Machine learning and use of both horizontal and vertical system information flow. Eventually, after the analytics layer is proceeded, a deeper insight can emerge from the structured comparisons and patterns. *"Linking combinations of readings to the occurrence of problems can be useful, and even when the root cause of a problem is hard to deduce, those patterns can be acted on."* (Porter & Heppelmann, 2015 a, p. 7) The use of data lakes can be applied with different integration with respect to organizational need, (Hagstroem, et al., 2017) proposes a four stage integration model each with different capabilities with respect to strategy, application and results.

Tabell 1: Data Lake Integration (Hagstroem, et al., 2017, p. 3)

Stage 1, Raw Data landing zone	Stage 2- Data Science environment	Stage 3- Offload for data warehouse	Stage 4- critical component of data operations
Data lake is a low cost scalable "pure capture environment"	Data is actively used as a platform for experiments	Data lake is integrated with existing enterprise data warehouse	Data lake is a core part of the data infrastructure

The big data analytics and data management and smart connected products are related to the convergence of IT and OT Systems and the challenges these pose. The Dev-Ops need to know IT and OT differences and characteristics to make decisions on strategies for performance and cyber security.

3.3 Information Technology (IT) & Operational Technology (OT)

Smart connected products, IOT and big data requires some form of integration between operational technology and information technology. (Porter & Heppelmann, 2015 b).
However, there are some challenges for a fully integrated (looped) system for the future industry 4.0 environment, and its due to the different objectives and fundamental priorities the systems have. Operational Technology is a engineered system for monitoring and controlling industrial processes, while a IT system has an architecture that is created for dynamic changes. These systems have intentionally been separated from each other due to the function but also due to the constant threat of cyber-attacks in internet systems. According to (Novotek, 2018), the difference between IT and OT are their priorities, and highlights especially the "Tuesday patching" (Novotek, 2018, p. 1), as a challenge to process integrity.
The key differences are extracted from (Novotek, 2018, p. 1) article on the subject,

Tabell 2: Difference between IT & OT Fundamentals (Novotek, 2018, p. 1)

Operational Technology Attributes & Priority	Information Technology Attributes & Priority
Deterministic: OT systems are engineered for specific, measured, prescribed actions based on content, and not context.	Dynamic: IT has a an array of attributes and exploit variants ranging from network, to applications and computing.
Process : Focus on reliability	Data: Availability
Few Gateways	Many Gateways
Control is Priority	Confidentiality is priority
Data throughput is secondary:	Data throughput is important :
No Patching : process is critical, can´t allow any security breaches	Patching is normal: seen as a necessity

As smart connected products, IIoT products and sensors are collecting data which is processed in the IT systems, the integration and connections between software, OT and IT is getting closer. Development of systems for this application is emerging as digital twin platforms in the industry now. The Dev Ops must be aware of challenges related to new processes, uncertainty and a new environment *"Clearly, digitization is a double- edged sword – while it promises efficiency and productivity, with relatively small capital investment, it also requires non-traditional human resources, new processes, organizational structures, and relationships within the IT/OT digital ecosystem."* (S. Z. Kamal, et al., 2016)

Tabell 3: IT, OT & Integration Technologies examples

Operational Technology	Information Technology	IT & OT integration
Supervisory Control and Data Acquisition, (SCADA) Human Machine Interface HMI, Remote Telemetry Unit RTU, Sensors and Actuators Programmable Logic controller (PLC) Distributed Control System (DCS)	Operative Systems Cloud service Data Lake Analysis Software Machine Learning Big Data Analytics Artificial Intelligence	IoT & IIoT Smart Connected Products Digital Twins Cyber Physical Systems RAMI 4.0

3.4 IIoT products, Smart Sensors and Smart Connected Products

A smart connected product relies on several things to add value for the environment, the functional attributes are the ones that makes it viable, but this section describes some of the things that make it technically possible to create and connect a smart product to the infrastructure. Because the products of the industrial internet of things are inflicting and controlling processes in hazardous areas, means that a missing or faulty signal can potentially be harmful for both humans and assets, this highlights that when IIoT is used, reliability of the components are not optional (Dudley, 2017), and really differs the IIoT from IoT.

The traditional operational technologies has their specific applications and processes to control, this in turn have created operational silos of information, that isn't viably open for the rest of the organization to access. The connectivity of IIoT devices are changing this as the *"The overarching goal of IIoT connectivity is to unlock data in these isolated systems ("silos") and enable data sharing and interoperability between previously closed components and subsystems (brownfield) and new applications (greenfield), within and across industries."* (Joshi, et al., 2018, p. 9)

It was General Electric (GE) that coined the term Industrial Internet of Things in the end of 2012. And it was described as "*a network of multitude of devices connected by communication technologies, combining machine-to-machine (M2M) communication, industrial big data analytics, technology, cyber security, and HMI and SCADA, the IIoT is driving unprecedented levels of efficiency, productivity, and performance"* (GE Digital, 2018, p. 1)

On a component level, the IIoT product includes several components to leverage this ability, and which is composing a smart connected product. these devises are is sensing, analyzing, reasoning, acting and communicating with people and other devices, creating possibilities for monitoring, and controlling things that needed physical effort to manage. To do this, the combination of sensors and actuators, computational power, network connection and power supply is needed. (Serpanos & Wolf, 2018) This is somewhat hardware based, but mostly software driven, and the software developers are leading the way with new business "As a Service" model

Since the introduction of microprocessors and software, the evolution of transistors and operating platforms have changed the cost structure of sensor networks in industrial applications. Hardware costs have fallen, giving consistency to Moores law on the halving time.

A visual representation of the trends was published by (Buchheit, 2018) in the journal of innovation by industrial internet consortium.

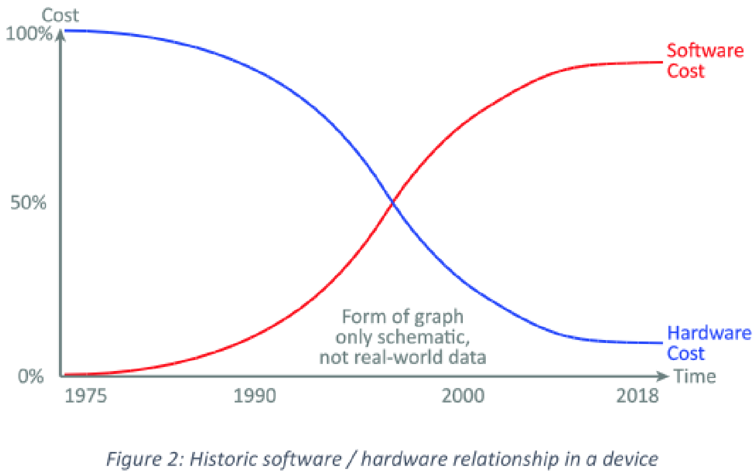


Figure 10: Software/hardware cost relationship (Buchheit, 2018)

The hardware part is sensing and function as a infrastructure, while the processing and analytics are software based, both will be elaborated in the following sub chapters.

3.4.1 Traditional Sensors, Sensor System and Signal Processing

A sensor is defined as and has the job of converting analog physical states into electrical signals (Wilson, 2005, p. ix). There is a vast amount of sensors out in the market branded with different names and specifications. *"Understanding sensor design and operation typically requires a cross disciplinary background, as it draws from electrical engineering, mechanical engineering, physics, chemistry, biology, etc. "* (Wilson, 2005, p. ix).
Sensors are a central source of information both for control and monitoring of processes, and for making the OT systems automatic and safe. (Electro Chemical Society, 2018) *"Sensors science and engineering is relevant to virtually all aspects of life including safety, security, surveillance, monitoring, and awareness in general"*. (Electro Chemical Society, 2018, p. 1).
However, the sensors do not operate by themselves, and must be part of a larger system with components that conditions and processes signals, working as a measurement system. (Wilson, 2005) The transformation from a physical change to valuable information requires a composition of material and physics theory, a hypothesis and practical experimentation for validation. These are related to measuring attributes of processes and connecting it to physical changes in the process or system health.

Hence, a proper signal transformation is crucial for addressing changes.

A sensor must be able to transform the changes into raw information, this can for example be measures on vibrations, temperature or light. The transformation to contextualized information requires the raw data to be transformed to digital values (0,1) called a Analog to Digital Conversion (ADC), which then makes the signals available for software filtering and further processing. Typical methods for signal processing are related to amplification, impedance transformation, linearization and filtering. (Wilson, 2005)

In a typical industrial application there will be a loop where a signal from the sensor generates information to the operator, or automatically forwards the signal to a transmitter Also known as a DAC (Digital to Analog Conversion) that actuates a process for regulation.

3.4.2 Sensors Types

Sensors are often defined by the thing they measure, but are by industry professionals and experts denoted by "Types", Tabell 4. The type of sensor that applies to the physical phenomenon that is measures, and the active/passive column refers to if the sensor need active power supply to give signals, or if its passive and generates signals with no power supply. The output is referring to the signals the DAC is receiving and transforming to digits.

(Wilson, 2005). Selecting a fit for purpose sensor is very important, and can be crucial for being able to measure the physical phenomenon at it rate changes, and the signals it gives.

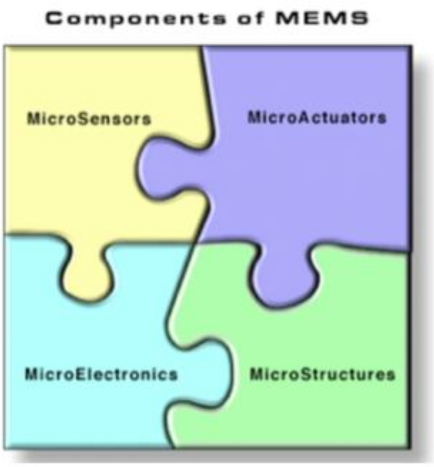
"If the data is distorted or corrupted by the sensors, there is often little that can be done to correct it" (Wilson, 2005, p. 23)

Tabell 4: Typical Sensors and their output (Wilson, 2005, p. 17)

Measurement	Types	Active/ Passive	Output
Temperature	Thermocouple	Passive	Voltage
	Silicon	Active	Voltage/Current
	RTD	Active	Resistance
	Thermistor	Active	Resistance
Force/ Pressure	Strain gage	Active	Resistance
	Piezoelectric	Passive	voltage
Acceleration	Accelerometer	Active	Capacitance
Position	LVDT	Active	AC Voltage
Light intensity	Photodiode	Passive	Current

3.4.3 Smart Sensors & MEMS

Smart sensors can be composed of Micro Electric Mechanical Systems (MEMS), which are at chip size (micro meter). The basic elements of a smart sensor is the microcontroller, a high resolution Analog Digital Converter (ADC), Amplifier and the sensor (Wilson, 2005, p. 20)
The smartness of smart sensors is related to self-calibration, linearization, Interchangeability and Standard Digital Interfaces (Wilson, 2005), which makes it efficient to connect to OT systems (Fieldbus), and its easy to change, and reliable.
Current technology allows for production of nanoscale structures and micro scale sensors. Micro Electric Mechanical Systems (MEMS) is an integration of Nano components on a small chip to create a micro system. This micro system can both process information and sense and act to physical changes (smalltechconsulting, 2018). A sensor or actuator is often referred to or categorized as a transducer, meaning that the device converts an input energy from one form (physical or electrical) to another form (MEMSnet, 2018). Figure 11: Components of MEMS (MEMSnet, 2018, p. 1) illustrates the building blocks of a micro electric mechanical system(Left) , and a picture of a 200 μm surface micromachined resonator fabricated by the MEMS and Nanotechnology Exchange MNX, MEMS component (Right)



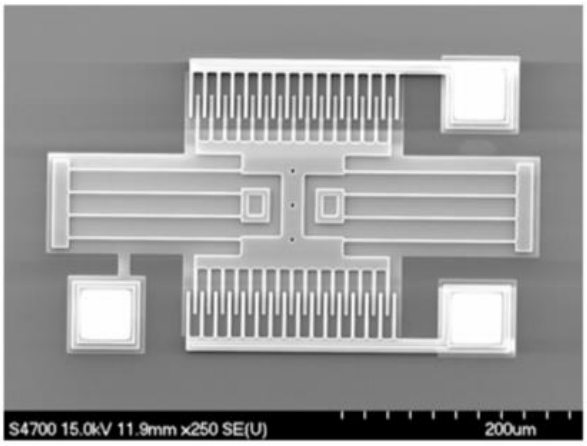


Figure 11: Components of MEMS (MEMSnet, 2018, p. 1)

During the past decades, MEMS researches has demonstrated that MEMS sensors actually is outperforming micro scale sensors (MEMSnet, 2018). The developers has created sensors for many sensing modalities such as pressure, inertial forces, magnetic fields, temperature and radiation. MEMS devises both sense, think, act and communicate and has application areas where miniaturization is beneficial. Sensors that is often miniaturized and the typical applications are Accelerometers, gyroscopes, pressure sensors and chemical sensors.

(Southwest Center for Microsystems Education (SCME), 2011) These sensors are essentially in all smart devices, such as mobile phones, smart homes, industry applications and in automotive industry. Some application areas in the automotive industry that are using these four typical sensor types for are highlighted by (Southwest Center for Microsystems Education (SCME), 2011) Airbag Deployment, “smart” sensors for collision avoidance and skid detection, Active suspension, Navigation, Antitheft and Headlight leveling and positioning

3.4.4 Analytics, Edge and Cloud

A smart connected product can take advantage of the technical attributes to become smaller, faster and more reliable. However, it is the data analytics and insight the smart connected product is giving, that accounts for added value. Although all these methods for analyzing data exist, it may not be practicable for all products to use them, “*Ultimately, it is the derived information (not the raw data) and how it can be acted on that determines what kinds of analytics are deployed, and where”* (Anderson, et al., 2017, p. 13)

The edge technologies is enabled with more powerful processors and low energy consumption which enables low latency processing and actuation because its embedded in the device, this type of processing is often related to baseline analytics (real-time data) processing.

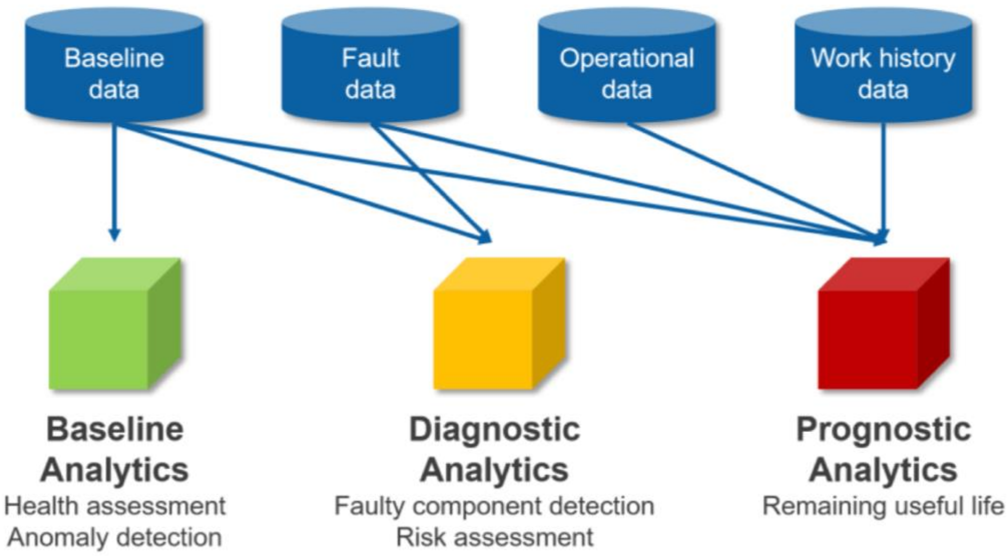


Figure 12: Analytics (Anderson, et al., 2017, p. 18)

- Baseline analytics is used for detecting irregularities in the operations and can react in a quick manner on these.
- Diagnostic analytics is determining, or assessing root causes of the problem, using techniques such as frequency mapping with Fast Fourier Transform FFT, and connecting physics to hypothesizes for determining faults.
- Prognostic analysis assesses the remaining useful lifetime of the asset, and is connecting to many sources and requires more computing power

(Anderson, et al., 2017)

While baseline analytics can be achieved by the processor of the product, the two other methods are using more processing power and needs connection to other data sources and more advanced software. This can be achieved by connecting to a cloud solution, providing an infrastructure for using AI to process vast amount of data in the prognostic analytics. There is two branches of AI commonly used for sensor data analysis, these are related to machine learning and deep learning. And uses two generalized techniques known as supervised algorithms and unsupervised algorithms. Where supervised algorithms uses datasets of "fault states" and "functional states" as a training of the machine learning software for detection of common faults in the machine/system. The other is unsupervised algorithms can use many methods, but one of them is known as clustering, and looking at it as a group of data. If the data grouping is diverging from normal, system health is changing. (Anderson, et al., 2017)

3.4.5 Networks for Smart Connected Products / IIoT / Sensor Networks

Smart connected products, sensor networks and IIoT is known for their networking capabilities as a common strength, while wireless communication is mostly mentioned, in the industry the traditional networks are using wired connectivity, these types of networks have different benefits depending on application (enviromon, 2018). Industry trends are changing this also to be wireless as the industry matures. The sensing, processing and communicating job of IIoT devices are affecting the power usage, although new methods for powering devices are being introduced. The selection of network protocol relies heavily on the amount of data/time that is needed to communicate. With edge processing, the network transfer rates are affected, and knowing the communicating rate is important in network selection. The available networks today can be siloed in four categories , Cellular, Low Power Wide Area Network (LPWAN), WI-FI, and satellite in the figure from (Alsen, et al., 2017), Regular networks are assessed with respect to bitrate, power consumption and range. The figure is elaborated with an overlay of all the relations. The Low Power Wide Area (LPWA) Network is known for facilitating IOT devices with batteries and provides a wide area communication with low power consumption. (Alsen, et al., 2017, p. 5)

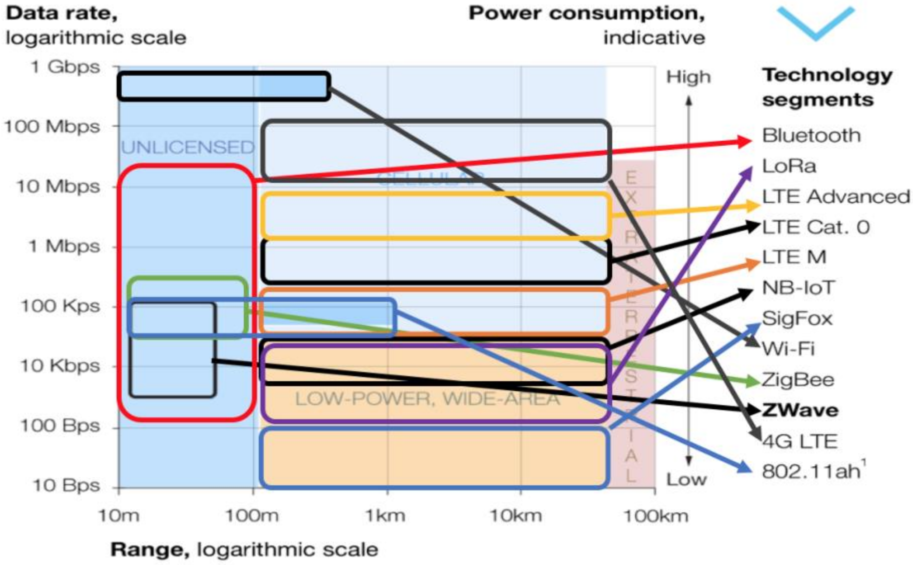


Figure 13: IOT Network selection (Alsen, et al., 2017, p. 5)

Connecting sensors to form a network working together has and can vastly improve application areas, safety, availability, maintenance costs and other important areas in the industry. *"The ideal wireless sensor is networked and scalable, consumes very little power, is smart and software programmable, capable of fast data acquisition, reliable and accurate over the long term, costs little to purchase and install and requires no real maintenance"* (Wilson, 2005, p. 575) Connecting a communication network of sensors can be done in multiple ways each having its positive and negative effects.

- Point to Point network topology (Mesh Network)
  Has high reliability as all the products/nodes are connected and communicating, is more energy consuming than the others

- Star network topology
  Is a hierarchical system, where it's only the base station that communicates out with each individual sensor, gives low latency.

- Tree network topology
  Combination of the two above, and is a hybrid system.

  (Wilson, 2005, p. 578)

3.4.6 Powering the: Smart Connected Product /IIoT Device /Sensor Network

The small connected sensors in industrial environments have usually been powered by wired networks, and also transferring signals to a field bus and SCADA system and getting power through the cable. This method, though highly reliable, is costly to deploy and challenging to scale (enviromon, 2018). New smart sensors & IIoT devices are coming with wireless communication protocols, an battery technology for the purpose of being able to retrofit existing machines and systems without connecting any cables (Pasero, 2018). There is in general three methods for powering IIoT, Smart connected products and sensor networks, either with cables, using batteries, or by an energy harvester, or a combination of them.
Energy harvester such as photovoltaic panels can be found on devices such as calculators.

New ultra-low power electronics are being developed, and the energy harvesters and batteries are increasingly becoming more powerful and uses of these are coming to the industry environment, ABB has developed an industry application for using these technologies with the WirelessHART temperature sensor, that is harvesting energy from the process that is being measured. *"The WirelessHART temperature sensor TSP300-W with Energy Harvester is powered by an on-board micro- thermoelectric generator (micro-TEG), which is driven by the temperature difference between the process and the ambient surroundings."* (ABB, 2015, p. 6)

Advances in battery technology is being made, traditional batteries such as AAA, AA and flat cell batteries are difficult to reduce the size of, hence the need for a new technology is needed. Small solid state batteries are now being developed, *"These solid-state rechargeable batteries measure a maximum 1 cm2, and are less than 1-mm thick. They also won't explode or catch fire. Because they don't have liquid components, they yield long lives, can be recharged thousands of times"* (Pasero, 2018, p. 1) The combination of using energy harvester and new small batteries together with low power electronics could provide to be a unique solution for creating long life and easy scalable IoT products for the industry (Pasero, 2018)

Section 4: Case Study, Adapting to a Changing Oil & Gas Industry

4.1 O&G Outlook

The recent 2014 oil price downturn has had a major impact on the industry stakeholders, from the upstream, to midstream and coherent organizations that have provided service to these segments in the down market. The sector is now beginning to recover as the upheaval is stabilized to maintain profitability resulting in a subsequent lower risk appetite amongst the industry leaders (Giorgio Biscardini, 2017).

A clear memory of yesterday's troubles and feats are still present, for now. As the oil price is gaining momentum, investors and allocated resources will come after and push the market once again, rising projects costs are inevitable as tolerances grow. When this stabilizes, other stakeholders , such as "*oil-field services companies will likely start taking back price concessions they gave IOCs when the market collapsed.*" (Giorgio Biscardini, 2017, p. 5)
The world have had its focus on OPEC and USA during the political oil price war that has affected the entire world wide industry, in the future however there are also upcoming players, Latin America (Giorgio Biscardini, 2017) will impose new activity on the world of E&P due to Mexico´s new energy development plans, which has opened for international competition in the search after deep water oil & gas. (Oil And Gas People, 2018)

Key trends in the business landscape are focusing on sustainable profitability, keeping their heads above water under multiple scenarios, differentiation and new business models that forms new collaboration between specialist companies. The digitalization and continuous development of technology will be explored by companies in the coming years. (Giorgio Biscardini, 2017). Although there has been a nervous industry since 2014, a survey conducted by DNV GL points to growing Optimism in the industry. 800 O&G professionals gave their outlook for 2018, resulting in findings that substantiates growing confidence levels, where 63% has positive vibes for the near future. The top priorities where Digitalization 37% and Cyber Security 36% (DNV GL, 2018)

4.2 O&G on the Norwegian Continental Shelf

4.2.1 Offshore Exploration & Production

Offshore O&G is revolved around Exploration & Production (E&P), which is commonly referred to as upstream O&G. This consists of exploring the offshore basin grounds for hydrocarbons with methods such as seismology and exploration wells. When a exploration is thought to be viable for further development into a production field, a new process is started and a project development phase is initiated. In this phase of Engineering, Procurement and Construction (EPC) the combined effort of organizations are managed the creation of new platforms (EKT Interactive, 2018). Energy and Production E&P have complex and multifaceted projects that involves many business partners, the Johan Sverdrup project alone is about 12000 man-years of work for people situated around the world (Equinor, 2018). It is in this phase also that Øglænd System is providing services such as engineering support, site support and products to the platform topsides. When the platforms are finished with construction phase, they are shipped out to their field site for “hook up”, and this is when the mission is starting.
The operations on a fully integrated offshore topside is related to three main processes, these are Drilling and Wells which is drilling new exploration wells and maintaining the operational ones. Process and Process support is in charge of production, and separation of gas, oil and water for further transport to onshore facilities, and the last process is related to Safety and Utilities (Odland, 2015 b)

A wide specter of different structures are used to facilitate offshore oil and gas production. These are configured based on size of field, water depth, conditions, location and more (Devold, 2017). The types range from large Gravity based structures such as Statfjord ((NOM) & Lundberg, 2018) and Gullfaks, to smaller platforms connected in a Shallow Water Complex. And for deep waters, compliant towers, floating production platforms exist. (Devold, 2017) The top of the platform is usually referred to as the platform topside.

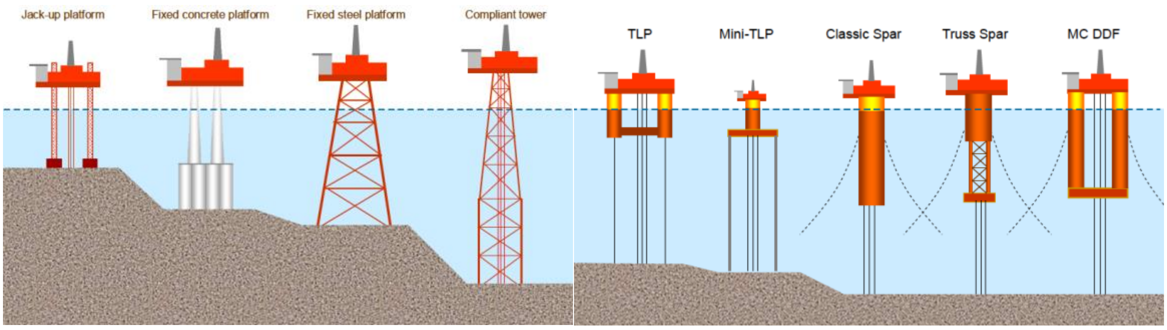


Figure 13: Offshore Platform Types (Odland, 2015 a), (Odland, 2015 b)

4.2.2 Life Cycle of Offshore Projects on the Norwegian Continental Shelf

The life cycle of an offshore project is comprehensive and has seven stages on the Norwegian Continental Shelf (NCS), the entire project from start to finish can range in lifecycle on 10-40+ years. The first phase consists of concession rounds and exploration and drilling appraisal wells for estimating size of discoveries. Thereafter is the project development phase and operations, it is the operational phase that is the longest (Odland, 2015 a)

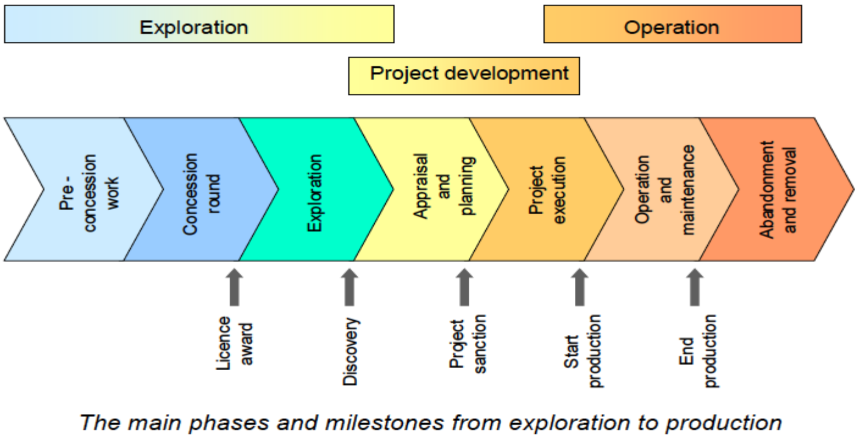


Figure 14: O&G project Life Cycle (Odland, 2015 a)

An O&G installation is constructed over several years before its shipped offshore and starts producing oil and gas. In the field development phase there are very high activities on building modules and coordinating the construction of the Topside. It is in the EI&T domain of the supply chain Øglænd System is registered as a business partner at (Norwegian Energy Partners, 2018)

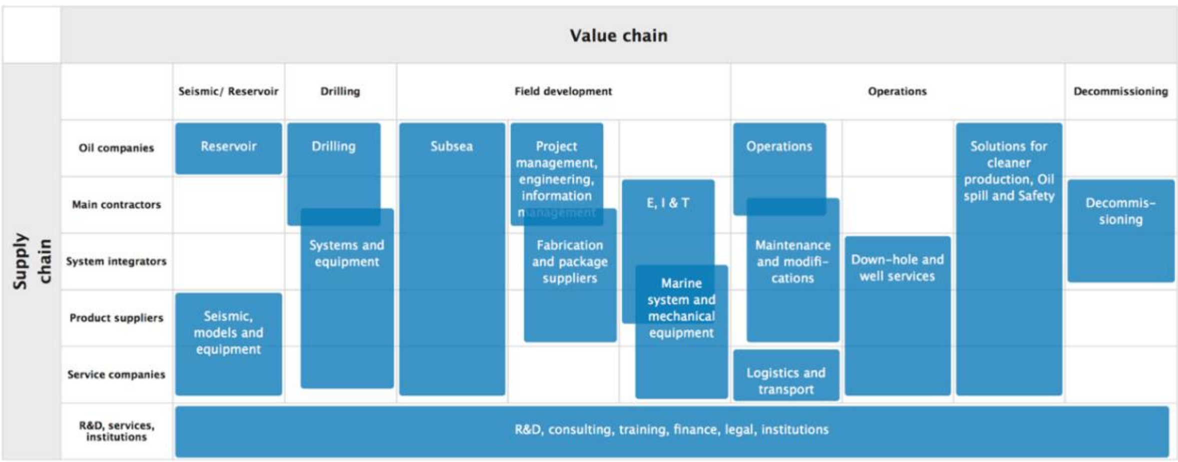


Figure 15: Value Chain (Norwegian Energy Partners, 2018)

4.2.3 Platform Topside Operations & Maintenance

The products on an offshore topside platform is constantly challenged by the operations and the harsh environment, consisting of salt water, sour rain, chemicals, oil and more. As a product provider to the O&G industry, these challenges have been addressed with adapted quality standards, and best practices assembly and maintenance routines. Looking into the challenges and current practices of maintenance on offshore topsides is an important aspect for improving products. The operational phase of a offshore platform has the longest duration in the E&P project lifecycle. This can range up to 40+ years referencing to Norwegian fields such as Ekofisk (est. 1971), and Statfjord (est.1979) which are to date, still in production.
Production of oil and gas on a topside has day to day operations consist of producing and separating water, oil and gas for transport while maintaining safety and efficiency. As the production degrades due to pressure fall in the reservoir, maintenance of wells and drilling of new ones are a strategy to extend the life of the field and increase Return On Investment (ROI). (Verdensklassen,, 2018)

The harsh environment and daily use of equipment leads to degradation and the need for maintenance to repair to avoid dangerous situations, or conditions leading to unnecessary stop in the production, processing or drilling operations. It challenges the products that is exposed *"The platform's equipment is exposed constantly to penetrating, corrosive sea air. That's in addition to the typical, yet severe, mechanical stresses that all platform equipment endures during day-to-day E&P operations, which makes maintenance all the more critical to uptime and productivity"* (Ileby & Knutsen, 2017, p. 60).

Traditionally, maintenance offshore has been a time based scheduled approach where components and systems are being replaced after a certain time interval. Some equipment have inspection based maintenance routines, this is typically bolts and corrosion related problematics. *"Preventive maintenance activities can be either calendar time based or operational use based, meaning that the maintenance activities planned are based on either fixed time intervals or on accumulated operational/running time"* (Ravnestad, et al., 2017, p. 3)

O&G is taking these challenges serious, and has started new strategies for addressing them with technologies comprising of Condition Monitoring(CM) and Condition Based Maintenance (CBM). The operators on the Norwegian Continental Shelf (NCS) has found that there is potential for increased Operational Efficiency and reduced life cycle cost by introducing condition monitoring (CM) on offshore equipment. "*While used in other industries for years, CM is an emerging trend in oil and gas E&P, as a means to reduce OPEX costs, increase regularity, and improved operational safety.*" (Ileby & Knutsen, 2017, p. 62). On the NCS, O&G majors such as Equinor and AkerBP is transforming towards fully integrated operations, which is closer cooperation between offshore and onshore personnel, and closer cooperation with operational industry partners (AkerBP, 2018). Equinor Integrated Operation Center establishment in 2018, is utilizing existing condition monitoring equipment and specialist centers and will also utilize interdisciplinary resources (Equinor, 2017) Future fields like Johan Sverdrup (Equinor) and the newly established Ivar Aasen platform (Aker BP) are utilizing condition monitoring. (Ileby & Knutsen, 2017, p. 62). Some topside assets are being monitored with online CBM on rotating equipment such as pumps, valves and electrical equipment.

For static equipment the use of corrosion-erosion coupons, manual sampling and inspection is common way of detecting degrading assets and integrity. The use of failure is by using Non Destructive Testing NDT methods, such as ultrasound inspection is also used on pipelines to detect cracks and scaling (Chai, et al., 2011) (Technical-Advisor, 2018) With a digitalized offshore industry, the possibilities of taking the maintenance strategies to a new level based on sensor data, and big data analytics (Equinor-Informant, 2018)

4.2.4 Operational Technology on Offshore Topsides

The systems offshore is managed by the Supervisory Control And Data Acquisition (SCADA) type systems, which has been described in section 3. This system is controlled from the central control room (CCR) on the platform, and is essentially managing overviewing all the processes on the platform. A combination of graphical illustrations, process lines, alarm settings and historical data readings are used to control the processes in the production facility, with modern SCADA systems, the information in the control room is also available in the onshore support center. (Devold, 2009) *"Large plants with up to 30.000 signals to and from the process requires a dedicated distributed control system"* (Devold, 2009, p. 69).

According to (Inductiveautomation, 2018) a SCADA system typically consist of these components, Sensors and actuators, Programmable Logical Controllers (PLC), or Remote Telemetry Units (RTU) and a Human Machine Interface (HMI).

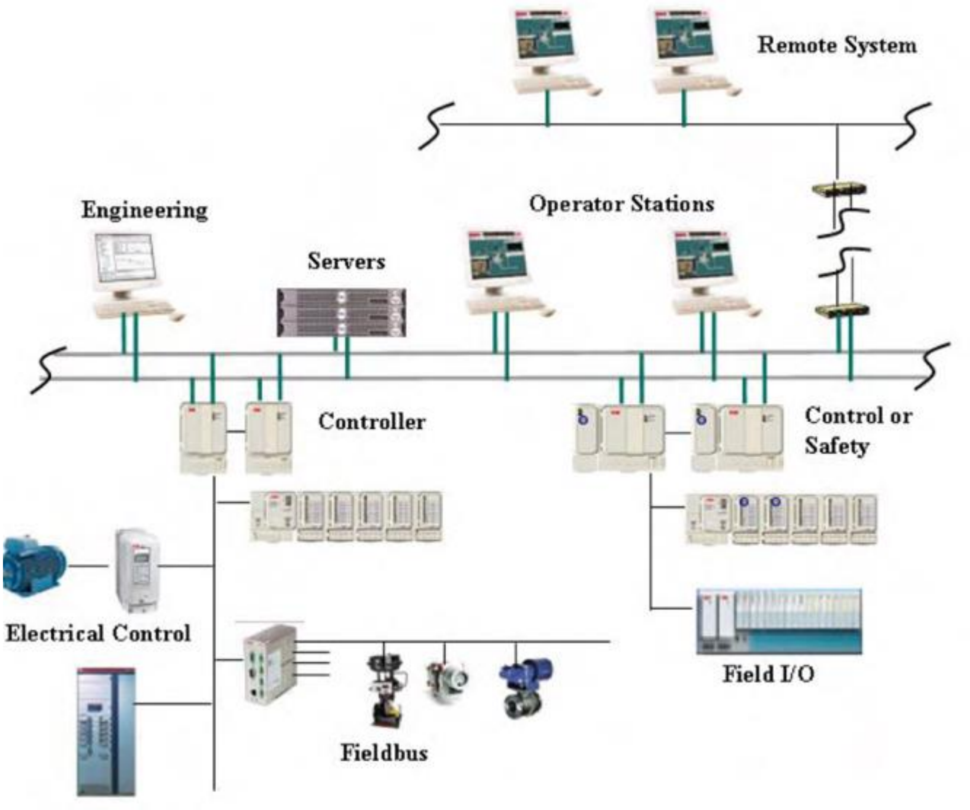


Figure 16: SCADA System Offshore (Devold, 2009, p. 69)

4.2.5 Sensors and Electrical Equipment Offshore

Sensors that is to be used in the offshore industry segment often requires certifications in line with demanding standards such as EX,(Safety Integrity Level) SIL, and CE to encompass and not be a product that increases risk on the plant. Field sensors and devices in process areas must be encapsulated to prevent them for becoming an ignition source.

A offshore topside usually have three different zones where Zone 0 is the most explosive environment, inside tanks and pipes and near the wellhead area where the igniting energy of a gas cloud is low. Zone 1 is an area where there is medium risk of hydrocarbon and Zone 2 where there is low risk of hydro carbon leaks. (Technical-Advisor, 2018)

Smaller sensors demand lower energy consumption and the development towards smaller sensors make the need for encapsulation size smaller and hence easier to protect. (Technical-Advisor, 2018). There are three different ratings for product encapsulation from the most heavy Safe by pressurization EX.p, safe by explosive proof encapsulation. EX.d or intrinsically safe EX.i. (Devold, 2009)

The standard way of connecting sensor networks has been with a wired network sending the signals trough a field bus (shown in figure 18). New communication technology and a better framework for implementation has started to introduce IIoT devices in the offshore topsides.

The network topology that is used together with communication protocols often make them more reliable than if it had been hardwired, this is due to the peer to peer network topology sending signals in the network independent if every smart sensor product is forwarding the information, and the encryption that is used between them. (Technical-Advisor, 2018)

The traditional places to use sensors is in offshore facilities to monitor volumes, pressure, and energy, to control and monitor valves for controlling these values. With digital twin and cyber physical systems the sensor technology can also be utilized for big data analytics and also for condition based maintenance. The highest focus has been on rotating machinery and using advanced analytics for monitoring the condition on and forecast the development of initiating faults. The use of sensors on static equipment is also possible, but the contemporary practices are inspection routines. *"In the case of topsides static process equipment, inspection is often planned and executed according to the principles of Risk-Based Inspection (RBI)"* (Chai, et al., 2011, p. 668).

4.3 O&G Digitalization on NCS

The future O&G will be using state of the art digital tools, and the transformation to a new digital infrastructure is targeted by O&G majors, Equinor has targeted 2020, and elaborates how Johan Sverdrup will have these digital capabilities through the digital twin. (BRAND STUDIO , 2018) It´s about changing how things are connected, presented and found. This enables a new more flexible way of collaboration, and reasoning of contextualized data.
Digitalization as reviewed in section 1 is leveraging the (Rüßmann, et al., 2015), nine pillars of technological advancement, and transforming from a traditional Operational Technology SCADA user to leveraging a new CPS and a Digital Twin with real time data.

System integration, IIoT, AR, VR, Big data analytics, machine learning and simulation, are technologies that is implemented for working smarter, more efficient and safer. The O&G organizations have opened their eyes for implementation of new technology and are seeing the value of data sharing. They are all wanting the same solutions, the big economies are not driven by O&G major actors as it was in the early 2000´s. the new leading business economies are IT organizations that leverage data and data sharing. (Cognite-Informant, 2018)
Digitalization at an industry 4.0 level requires a well-funded framework for scaling of data and information flow. The O&G industry are now in the early stages of creating Cyber Physical Systems and Digital Twins, the digitalization level can be assessed using the 5C architecture (Lee, et al., 2014) The O&G industry are creating 3D models with integrated IIoT platforms for real time monitoring of processes and health condition. They are also innovating and exploring the field of Cognition level technologies, this categorizes the industry maturity to soon be reaching implementation of the cyber level, with experimentation on cognition.

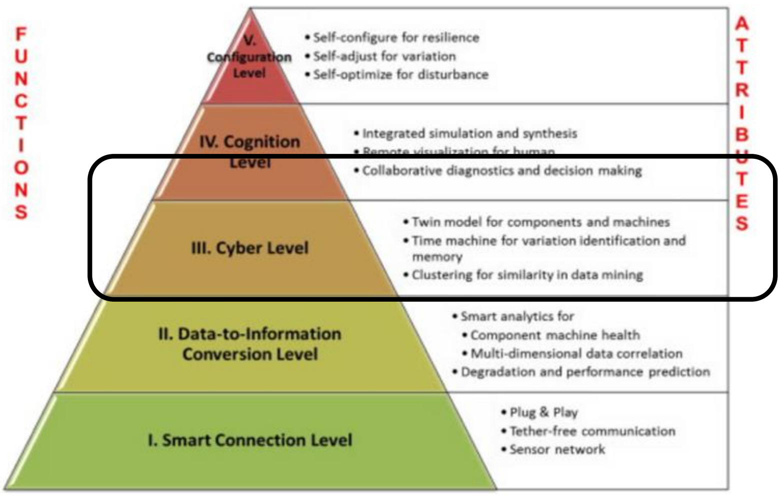


Figure 17: 5C Evaluated digitalization Level for O&G on NCS

4.3.1 Equinor Digitalization

Equinor has grand visions for the future digital organization and is investing heavily on digitalization of the ERP and Offshore operations. A center for digital excellence has been established to drive the necessary processes of transforming the framework, they expect to invest 1 to 2 billion NOK in this change. They see new opportunities in technology that can improve work processes, leveraging advanced data analytics and in the Robotics and remote control aspects. (Equinor, 2017) Using a roadmap with seven important processes for digitalization across the organization, improving "digital safety, "security and sustainability", "processes digitalization", "sub surface analytics", "next generation well delivery", "field of the future", "data driven operations" and "commercial insight". Equinor is targeting amongst others to harvest ideas and cooperate more tightly with industry partners. (Equinor, 2018)

4.3.2 Contemporary Status

Although the digital twin and digitalization processes are streamlining processes, the idea of keeping the 3D models updated have been present for some time. The 3D model strategy Equinor have been using in their projects stores much of the information and basis for construction in the model. It facilitates further lifecycle stages in EPC organizations workflow, and acts as a source of truth. The 3D models of assets serves as a modulator for the creation of building drawings that serves as a base for fabrication of steel structures, plates, pipe systems and all other equipment on the platform or plant. The model serves as a source of truth, and is used for follow-up of design and design reviews. (Equinor-Informant, 2018)

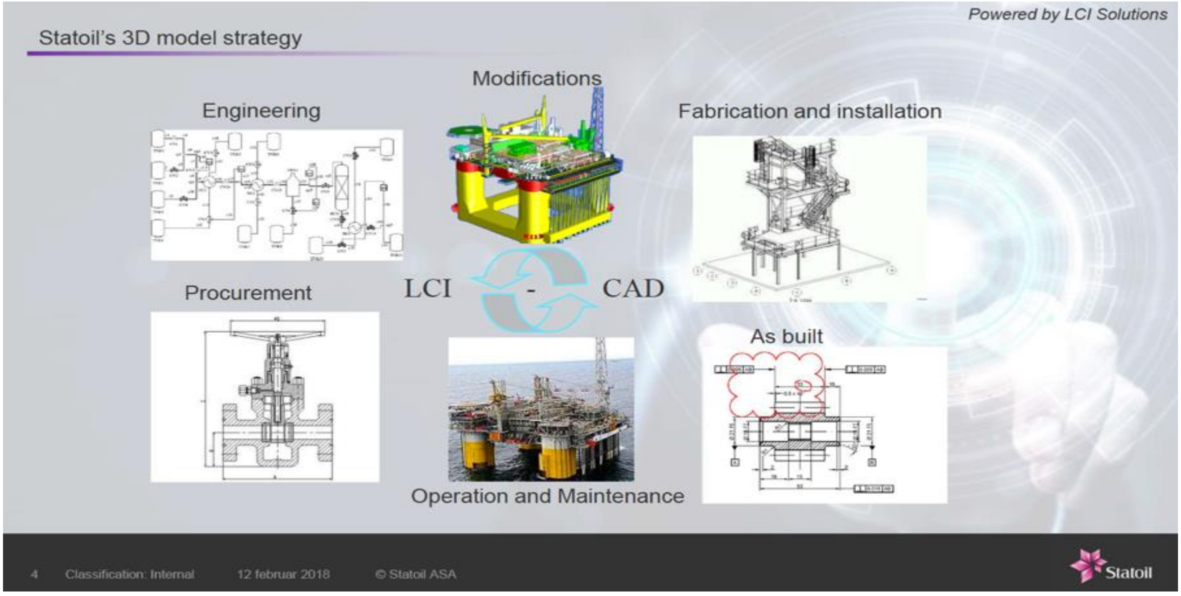


Figure 18: Statoil 3D model Strategy (Equinor, 2018 b)

All Equinor assets have updated 3D models, and their strategy is to maintain all relevant information updated at any time throughout its lifecycle, which is a part of the terminology: Life Cycle Information (LCI).Equinor has maintained and updated Process and Instrumentation Diagram (PnID) and 3D models, and have updated drawings and models that originated all the way back from projects started in 1980. (Equinor-Informant, 2018)

4.3.3 Equinor Digital Twin Concept

The illustration envisions a future connectivity within a digital twin framework, connecting sensor data, engineering data and the 3D model with the main objective is to monitor and optimize processes and maintenance on the plant, by using a digital twin one can visualize these objects and processes.

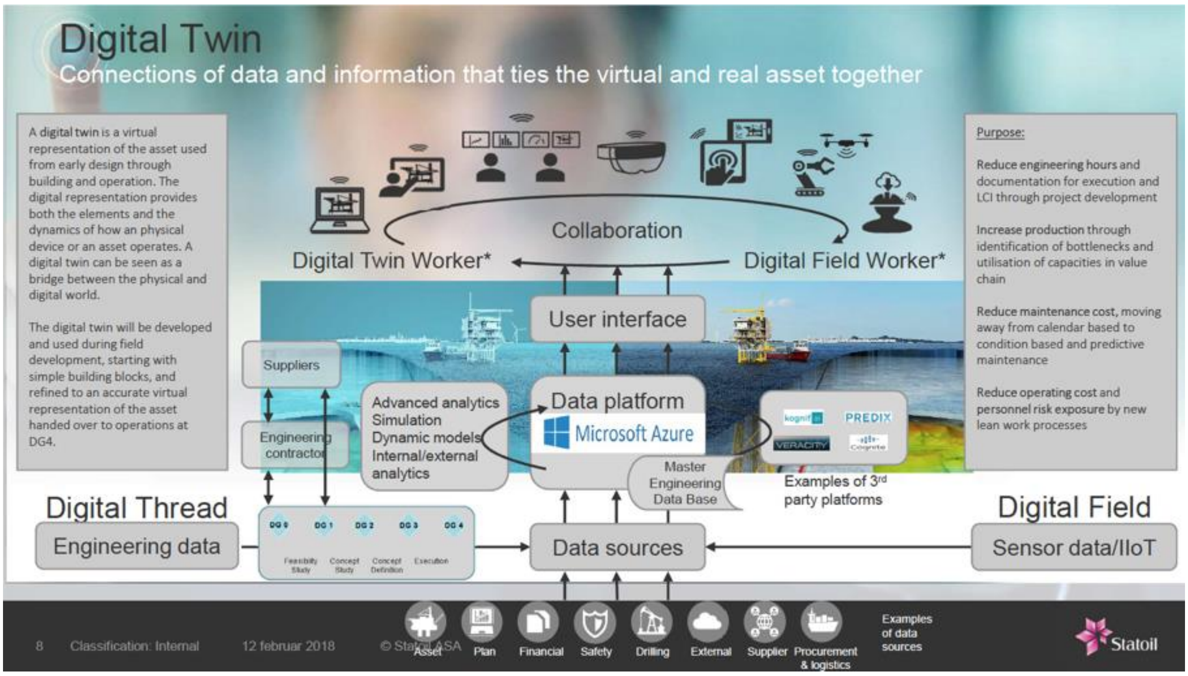


Figure 19: Digital Twin Vision Statoil (Equinor, 2018 b)

The difference between a 3D model and the new digital twin lies in the information life cycle processes. The digital thread is feeding engineering data into the database, and so is the digital field IIoT sensors, where all is available in the cloud solution for collaboration. The digital twin is envisioned to be held updated with maintenance and modification operations MMO that is utilizing for example scanning technology. And the operational phase of the asset will be able to contextualize and utilize sensor data at a much broader specter both with regards to big data analytics and process optimization but also in monitoring and fault investigations in a contextualized environment, maintenance strategies has historically been time-based, and not concerned about the objects actual condition, the future scenario is however based on advanced analytics, condition monitoring. (Equinor-Informant, 2018).

Equinor has a dedicated team that cooperate with Kongsberg Digital in development of these advanced analytics (Equinor-Informant, 2018), they are developing new technologies that in relations to the 5C Architecture is at Cognition level. Kongsberg Digital is proposing a future with simulators in the digital twin environment, and highlighting that the digital twin isn't complete without this feature. (Øyvann, 2018, p. 30). *"the digital twin is a tool which can help you visualize data, visualize documentation train on maintenance and create applications which tells you when you have a maintenance demand" says* Andreas Jagtøyen , (Øyvann, 2018, p. 30).

The next step is evolving the digital twin into an intelligent digital twin, leveraging all the sensor data from the physical asset into useful big data in the digital twin environment. This can be used together with machine learning, a branch of the term AI (Artificial Intelligence), Hege Kryseth from Kongsberg Digital, elaborates that *"some of the things you can expect from us this year is dynamic digital twins for tomorrows oil platforms"* (Øyvann, 2018, p. 31), which is combining physics simulators for process flow, component simulators and maritime simulators. Machine learning is the first step in realizing Autonome systems. Jagtøyen explains the logic behind this realization in Autonome Systems with *"the machine learning algorithm gets trained by the simulator, and trough this, all the data which is available in the twin".* (Øyvann, 2018, p. 31)

4.3.4 Cognite – An industrial Data Platform

The development of a digital twin platform isn´t an easy task, one of the pioneers in the O&G industry which are taking on this challenge is Cognite. As a part of Aker BP strategy for digitalizing the Energy and Production (E&P) segment on the Norwegian Continental Shelf, Cognite was founded as a digital company with a vision to deliver *"An industrial data platform empowering customers to leverage data as a strategic asset"* (Cognite, 2018, p. 1). The digital twin will visualize and contextualized real time raw data within a geometry representing the real asset. It´s their goal is to create a digital representation of the physical world with as much information as possible and make it accessible for others. *"At the heart of the Cognite solution lies in its ability to contextualize all industrial data types"* (Cognite, 2018, p. 1)

Figure 20: Cognite Digital Twin (Cognite, 2018)

Figure 20 shows the Ivar Aasen platform with contextualized information on pressure and temperatures related to real time data, it is contextualized with the actual 3d representation of the platform. The main technical challenges related to building a digital platform for everyone to use, is to fit a complex physical world into a generic data model without too much simplification. Data has value, and this value increases to a greater extent if everyone shares their data, the future competition will be in taking advantage of raw data, and be competing on analytics and optimization instead. The technology of digital twins have actually been available for at least 10 years, the recent crisis has however contributed as an wakeup call for the O&G sector into taking advantage of the technology. (Cognite-Informant, 2018)

The contextualization of information in the figure shows how signals in its simplest form can contribute to a add value to the large picture. It starts by connecting sensor values to metadata, which puts the values into information that an operator can understand such as Bar, Centigrade and frequencies. A sensor readout is then related to the actual equipment, and its placement in the system (PnIDs). When this is contextualized in a 3d model its easier for humans to create physical hypothesizes for condition monitoring and faults, which can be put into the models for machine learning in condition monitoring and process optimization which is connected to the maintenance logs and Enterprise Resource Program (ERP) data and even conditions such as the physical climate, wind and waves. (Cognite-Informant, 2018)

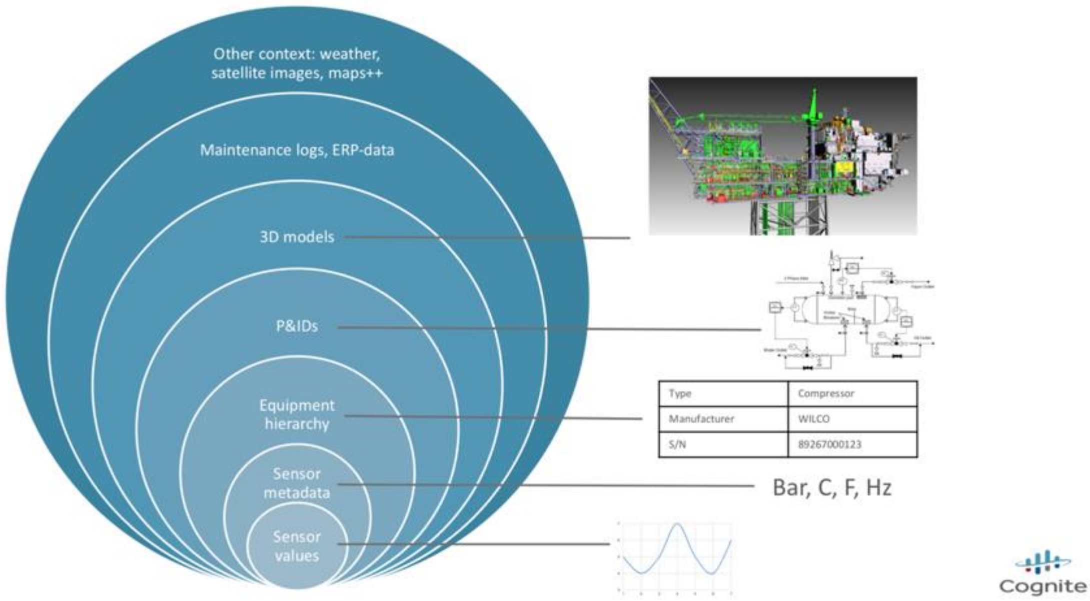


Figure 21: Sensor contextualization Hierarchy (Cognite, 2018)

Leveraging big data is not an easy task, but if it´s done in the right manner it can break down the silos of a complex installation where a large number of contractors has contributed to building the asset, and where teams with different functions on the platform can contribute and take use of the available data in the system. The 3D models are currently being “rolled Out” into operations offshore where operators use tablets, smartphones and goggles where they have access to real time information and maintenance logs by pointing the tablet on the asset. This also implies that the digital platform can support many operational processes in form of planning and information. (Cognite-Informant, 2018)

4.4 Emerging Trends in O&G Leveraged by Sensor Technology

As mentioned in previous chapters, the operational phase of the platform is can be optimized by utilizing sensors networks and analytics. The areas of focus for the E&P majors are related to process optimization and predictive maintenance, sensors do also integrate with HoloLens AR technology at a higher digital level. The environment in the offshore E&P platforms are harsh, and there is challenges related to corrosion, but there is also wear and tear on process equipment and piping systems, most pipelines are designed with an operating lifespan of 25-30 years, aging pipelines are prone to fatigue and material cracks in joints. these failure modes can be detected with a sensor network and a condition monitoring system. (S.Ravi, et al., 2016).

Work process optimization with the help of sensors and digitalization, new cyber physical systems are capable of real time transformation of data to an operator in the field with the help of HoloLens technology (Augmented reality, AR), or devices such as smart phones or tablets, the work flow is eased by the instant information flow to the operator when he/she points the device onto the asset of interest. (Cognite-Informant, 2018). Process optimization, is driven both by simulators, but also from the data that is captured during the operational phase. This data can be used as real data, and by using machine learning algorithms, the operating system can be further optimized.

Section 5: Case Description, Øglænd System AS

5.1 Intro

Øglænd System, founded in 1977, is a branch successor of the Jonas Øglænd AS
Originally they entered the market with non-corrosive cable management products in a time when competitors offered solutions of very limited life time. Øglænd System was known as a supplier of high end quality products which gave them the differentiation they needed for the offshore industry. (Øglænd System, 2018)

A local factory, attitude and skilled personnel, with customer satisfaction as highest priority has been factors for the successful blossom of the company during the last 40 years. Its global footprint and products and services range has grown exponentially. Today Øglænd System is a world leading manufacturer and provider of cable ladders, cable trays, support systems and accessories, in addition to digital solutions and engineering services. (Øglænd System, 2018)

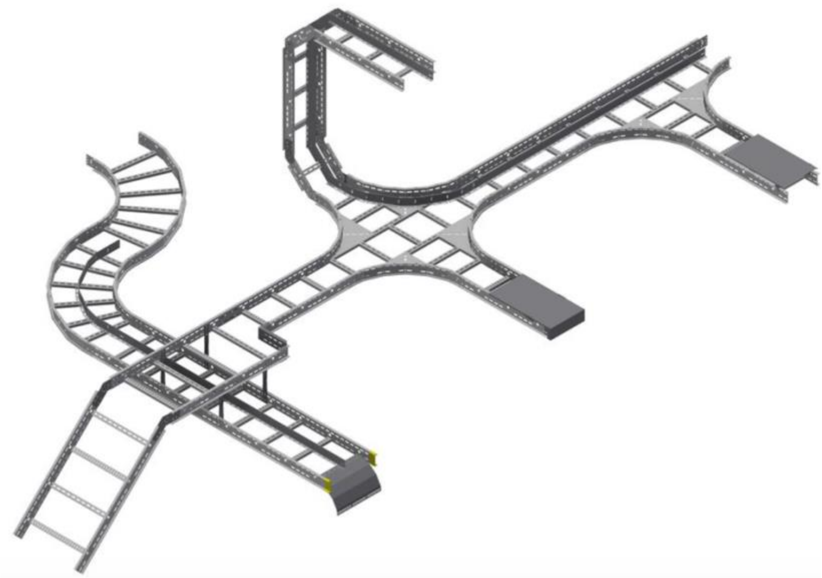


Figure 22: OE Cable Ladder System (Øglænd System, 2018 d)

The OE ladders is a successful concept for offshore usage, and has references to well-known projects on the NCS such as Statfjord and Vallhal (Øglænd System, 2018)
From then to now, the product offerings have changed and now consists of a complete support system in addition to the cable management system, and expanded into support of piping and HVAC in the offshore industry.

The support system portfolio is built up around the patented Mekano® triangular channel which was introduced to the market in 2010, this product has facilitated integration of technical offshore disciplines such as

- EI&T : Facilitating Electrical, instrumentation and telecommunication
- HVAC: Supporting HVAC systems in offshore modules
- Piping: Supporting pipe systems ranging from 1" to 8" pipes.

These categories are and has been instrumental in the company's success the last years.
There are several key attributes that makes Mekano® triangular channels competitive against traditional solutions such as welded supports and coldwork solutions, these consist of strength, rigidity, light weight and short bolts.

Figure 23: Mekano Triangular Channels (Oglaend System, 2018 g)

5.2 Value Proposition

Øglænd system offering is adding value by increasing assembly efficiency, reducing weight and reducing engineering hours and estimates that the total cost savings for the clients are roundabout 30%. And comprises of :

- 50% reduction in installation time
- 3% weight reduction, saving 300 tons of steel on a 10.000 ton topside.
- 30% reduction in engineering time
- Cold Work solutions (no need for welding)

5.3 Project Involvement & Engineering Support

The system products and services are primarily directed to customers of new build (Greenfield) projects, which generates the most complete solutions using the multigrid System, channels and accessories. Project involvement is also directed to modification and maintenance projects of existing operational assets (brownfield)

Øglænd System is offering, engineering and project support for clients around the globe. And as a system integrator and facilitator for other disciplines, knowledge on uses and integration techniques is important. All the products are available in digital 3D libraries such as AVEVA, Bently and PDMS readily available for application in digital assets. Besides from the digital offering of application, user guides and full documentation on the products are also part of the package.

The engineering department is leveraging knowledge in a wide specter, focusing on manufacturing techniques, application, design, management and structural analysis. The project organization is capable of delivering full documentation on products and systems, installation guides and maintenance guides, and onsite support. (Øglænd System, 2018 b)

5.4 Product Life Cycle

Øglænd System is integrating its products and services into plants, buildings and O&G facilities on a project basis, either an entirely new asset, or modifications on existing assets.
(Øglænd System, 2018 c) The systems that are installed in offshore assets are sold as maintenance free structures with vibration tight fasteners, effectively reducing the need for maintenance throughout the products operational lifecycle.

5.5 Multidiscipline Support System & Mekano®

The concept of integrating different disciplines in one support system is a strong argument for assessing these products as a EPC (Engineering Procurement and Construction) organization. Integration is facilitated by the multigrid starters welded in the ceiling of the module in a mesh pattern. This makes it possible to build the support structure at any place in mesh grid.
The Mekano Channels are flexible, lightweight and quicker to install than regular welded supports, and can be assembled back to back without the need for extra brackets (Øglænd System, 2018 d). in addition to this, the system is delivered with engineering support for structural analysis.

The system can be combined as shown in figure *Figure 24* The illustration shows how the starter brackets (1) be combined with the bolted Mekano support system (2) in a multidiscipline system for HVAC (3), Electric power(4), tubing(5) and piping (6)

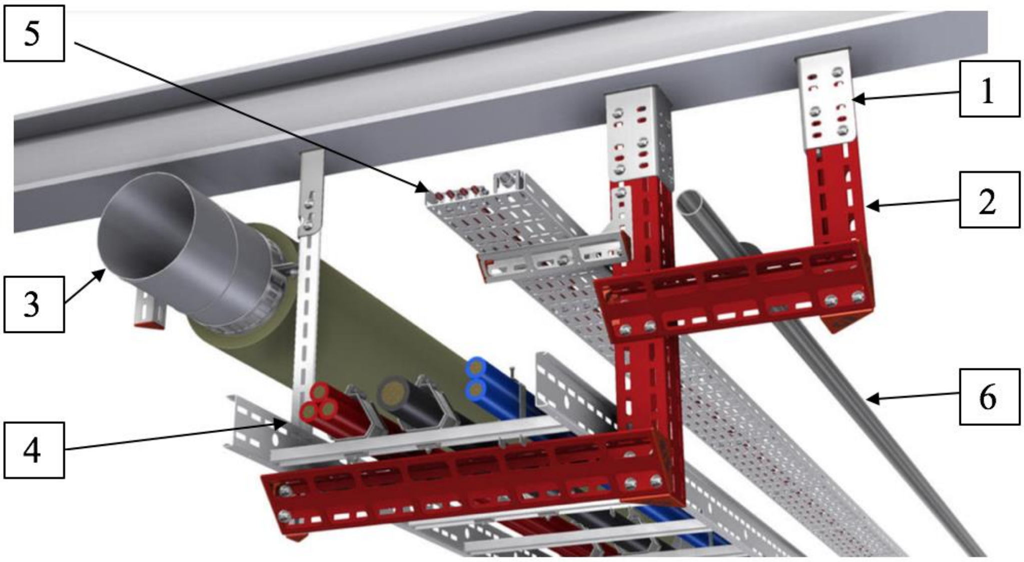


Figure 24: ØS Multidiscipline Support System (Øglænd System, 2018 d)

There are three different sizes of the Mekano channels, ranging from the smallest CH50-2T to the medium CH100-2T and the heavy duty channel CH125-2T5. Their common trait is their innovative triangular shape, which gives strength and reduces weight. The Mekano channels are together with the multigrid system are supporting important facilities and systems offshore consisting of the Electro, instrument and telecom (EI&T) discipline, Piping Discipline and Heating, Ventilation and Air Conditioning (HVAC) with special fastening products that will be elaborated on in the next subs.

5.5.1 EI&T Products

This category consists of support for Electrical, Instrumentation & Telecommunication wiring in industrial buildings, industry plants, windmill towers and ship hulls. This is the largest market for ØS Products. This product group also comprise of cable cleats for fastening and securing high voltage cables. From right to left, comprises of cable ladder systems(1), cable tray systems for lighter applications(2) and cable cleats for securing high voltage cables (3).

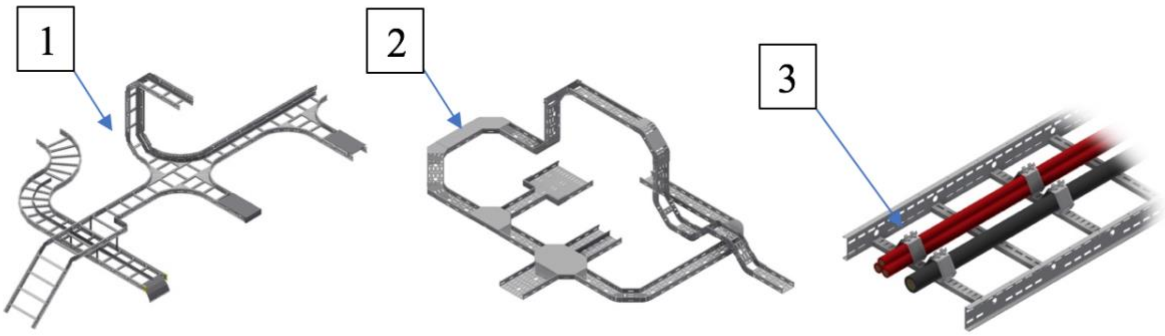
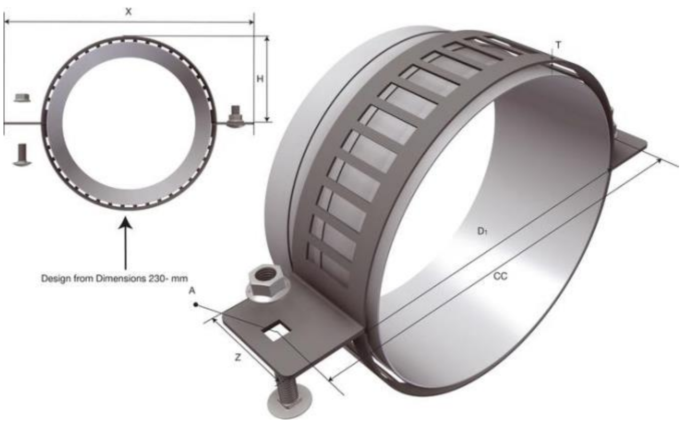


Figure 25: EI&T Cable Ladder, Cable Tray & Cable Cleat (Øglænd System, 2018 d)

5.5.2 HVAC Products

ØS has a complete HVAC clamp range consisting of clamps fit for insulated ducts and uninsulated ducts. The clamps are designed to minimize fitting space and can be fitted directly to the Mekano support system.



Figur 26: HVAC Products (Øglænd System, 2018 e)

5.5.3 Piping Products

The piping segment is oriented for process market and consists of clamps (1) and straps (2) for fixing pressurized and non-pressurized pipes ranging in size from 2” to 8” . The combination of standardized pipe clamping products adapted to the multigrid Mekano system has weight saving properties, faster installation and increased flexibility as positive synergies, comparing to traditional engineered welded pipe supports. For smaller pipe sizes, such as pneumatic controlling and hydraulic pipes are fixed using two different patents, INKO® and ETIN® (3).

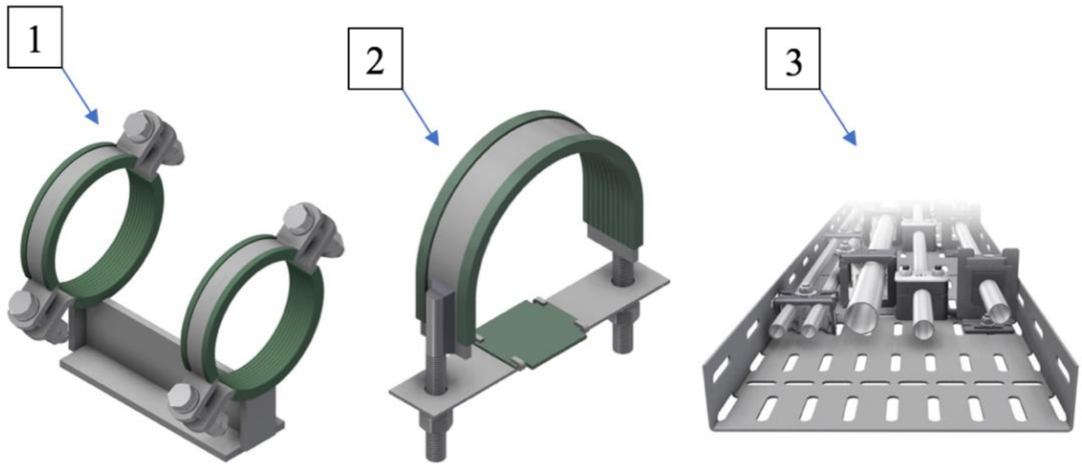


Figure 27: Piping Products (Øglænd System, 2018 f)

5.6 Øglænd Products in O&G Operational Phase

In the previous topics, the systems that Øglænd is supporting have been mentioned. This thesis is assessing the possibilities for using smart products in the operational phase of the O&G topside. However, since the products, their respective quality and maintenance free fastening methods are covered by the products attributes, a different approach to smart products or sensor systems will be assessed. As elaborated in the chapter on O&G maintenance trends, condition monitoring of systems and system health is a part of the new digital environment, and enriches the digital twin with more data. Adding data to the CPS will increase the value of the asset, and by looking into the disciplines and the possible monitoring techniques, one can assess the possibility for adding sensor systems on the current product portfolio.

5.6.1 EI&T systems

Electrical cables and systems are generally reliable and has a high "up-time" rating on O&G installations. And in general, power cables and instrumentation is everywhere on an offshore platform, and is the basis for enabling operations, thereby a highly important system.
Condition monitoring of high voltage cables has been deployed on some long cable spans, and has value for subsea cables, where the locating and fixing of broken cables have high costs. The use of acoustic waves in fiberoptic cables proved as an efficient method for locating the fault on one of these (www.optasense.com, 2018). The use of technology may also be useful on an offshore topside.

5.6.2 Piping Systems

In an offshore installation, piping is essential to both control processes and to retrieve the natural resources from the reservoir. The piping support is a strict engineering discipline that demands proper documentation and engineering due to the high criticality of the processes it is supporting. From the review of O&G in section 4, much of the current pipes on offshore topsides does not use online condition monitoring, but relies on periodic risk based maintenance and manual monitoring and inspections. New trends are emerging with the CPS and condition monitoring is getting integrated in the newest platforms. Piping systems are related to operations such as drilling and processing of oil and gas, but there is also facility systems such as water for cooking, and showering, deluge for firefighting etc. When these pipe systems malfunction or fail, the operational efficiency of the rig may suffer.
Due to the physics involved in transport of fluids and gases in industrial pipes, temperature, corrosion and vibrations induces stress on the system. And there has been some incidents on piping systems offshore. According to (Angulo, u.d., p. 1), *"Data published by the UK's Health and Safety Executive (HSE) for the offshore industry has shown that in the UK sector of the North Sea, fatigue and vibration failures account for 21% of all hydrocarbon releases"*
The problematics related to fatigue and the respective monitoring techniques are not elaborated in this thesis, but there is a upside in being able to leverage the technique of monitoring pipes with new technology as a condition monitoring sensor system would improve the reliability and safety of offshore facilities. As this seems to be a statistical repeating problem, *"Piping vibration failures have been one of the major causes of downtime, fatigue failures, leaks, high noise, fires and explosion in petrochemical plants."* (Tasintu, 2013, p. II)

5.6.3 HVAC Systems

HVAC is a field that is providing ventilated air to confined areas offshore, such as Living Quarters, Technical rooms, drilling modules, Process and drilling (AF Gruppen, 2018)
it is a fine tuned industry segment, with high focus on precision for air balance and volumes., Air intakes and exhaust gases from engines may induce vibrations in the structure.
The vibration monitoring of critical areas around intakes and exhaust for vibrating equipment Studies has been conducted on HVAC systems for these type of applications, and the methods proved viable for monitoring and controlling related to HVAC specific parameters such as motor bearing faults, heating, volume etc. (Sandeepan & Kavita, 2015)

Section 6: Adaptive Digitalization Strategy using Sensor Technology

6.1 Adapting to a New O&G Industry

The current state and the future of oil and gas will be optimized with new digitalization strategies that take advantage of the digital environment. A common goal for the O&G industry operators seem to be that they are wanting the same solutions, and if they collaborate on the framework for digital solutions, a standardized method for connecting equipment should arise. Having a standardized technical framework will simplify the industry partners and suppliers development and integration process and thereby creating a foundation for a more efficient, safe and reliable industry environment through new technology and work processes. The offshore industry digitalization is targeting especially two applications in the operational state of an offshore topside, this is process optimization and condition based maintenance (Equinor-Informant, 2018). Both aspects are leveraging high end technologies and is supported by technologies such as AI, machine learning, with data from IIoT and sensor systems and data from simulations, these technologies are functioning in the integrated cyber physical systems and is visualized trough the digital twin.

Technologies are used to leverage the assets ability to assess overall health and optimize the processes by making the infrastructure of operational data and information data available for pattern recognition, and using people with the right skillset and competence together with operational personnel. A better collaboration between the operational personnel and the control room is also facilitated by 3D visualization, real time data, and transparency and AR technology (Cognite-Informant, 2018).

Adapting Øglænd System products to have a role in the new digital environment requires some considerations on the ability to leverage product attributes, overall system function and add value for both O&G industry and Øglænd System at all stages of the strategy. A smart product/ sensor system is related to the use of the product, in this thesis the use is in the operational phase. Øglænd System products have good references on quality and application-friendliness from the offshore industry and partners, and the products are seemingly providing the function asked for. Finding a new function that can solve other challenges in the context of offshore O&G which can relate to Øglænd System products will improve the possibility for successful adoption by the customers. Simply putting sensors on the products for future use is a common thought, there will however come a time when important data is drowning in the noise of unimportant data, this will likely cause reactions in the industry (Cognite-Informant, 2018). The support systems are designed to support critical infrastructure on the offshore topside, some of these "cases" have been identified in section 5, this is however a batch of challenges, and there are probably more cases, with problems and opportunities related to the infrastructures that is supported by Øglænd products, which can be solved with smart sensors.

Indicated in chapter 5, all the systems, EI&T, Piping and HVAC, have their opportunities with condition monitoring, it is however the piping system that is indicated to have the most publicly available documented "problems" related to asset integrity, and poses a large risk factor for the O&G upstream activity. As Øglænd System is supporting these systems and have products that is fastening them, there is an opportunity for integration of piping products and sensors to help mitigate this risk. This will target to develop a product that can be defined as a "Smart Asset" (Raza & Liyanage, 2007) for the O&G upstream industry improving the overall system integrity. The context of Øglænd products in O&G industry will still remain the same but is adding a new feature for the industry to take advantage of for that is imposing safety, maintenance and process uptime and can serve as a modulator for extending the product with other sensors for other environmental measurements, for example temperature. This strategy is pursuing a new function that is in thread with the needs of the future O&G industry objectives trough studying the trending changes in the industry. The figure is illustrating how Øglænd System current product portfolio leveraged by Mekano® products the current services and vision is adding a new function trough digitalization and sensor technology, targeting "asset integrity" challenges and is adapting to one of the offshore O&G digitalization objective,

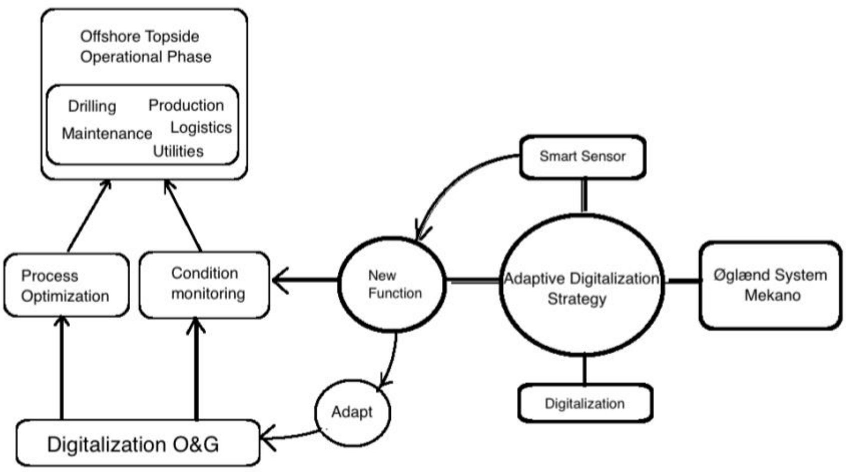


Figure 28: New Function

The sensor products can from this stage also explore the use of big data and transform from a sensor system, and a “smart asset” into a smart connected product, this requires a more fundamental transformation of the organizational structure and approach to change. Øglænd smart connected product can be a continues information channel that shares data with the environment on the use, condition and environment, which can be analyzed and acted upon both from an operational perspective, but also from a design and system perspective. This approach on product development is transforming the industry environment by using big data analytics, smart people and integrated cross-disciplinary design processes and sharing of data.

6.2 From a Product to a Eco System

The figure is inspired by Porter and Heppelman review of how smart connected products are transforming the competition in the industry (Porter & Heppelmann, 2015 a), and illustrates the current product use of Mekano® triangular channel as a product can be transformed to a smart connected product that has a function in the maintenance program on the rig, and how this maintenance program is connected to all the important functions on the platform. This system is being built in the industry environment, and is also illustrated in Cognite sensor contextualization hierarchy *Figure 21: Sensor contextualization Hierarchy*. Being part of a eco system also contributes to the common goal of adding value together side by side with other industry contributors by enriching the industry digital twin with more data, and by sharing data, both development and operations will improve with the available data. The existing product and eco system within a digital twin narrows the scope of development and can thereby utilize the existing network by creating a smart connected product.

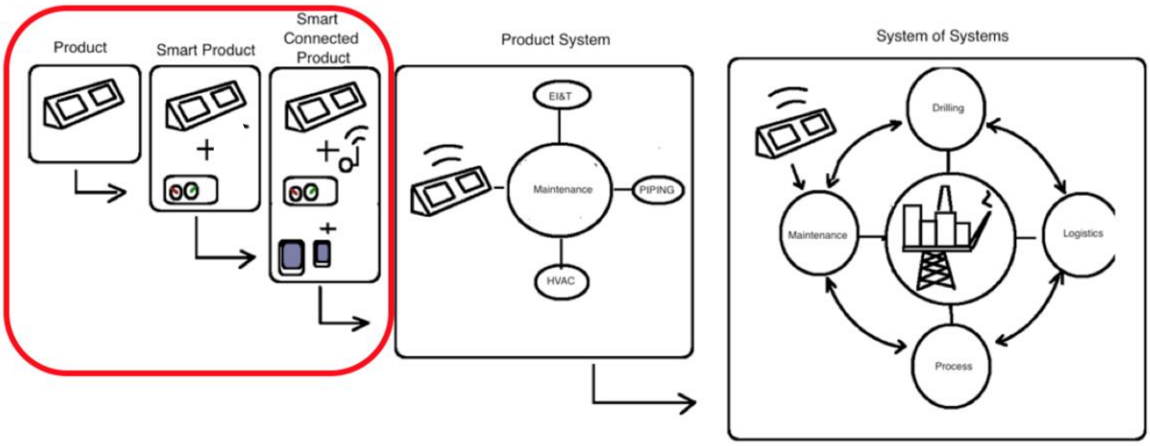


Figure 29: From Product to Ecosystem

The transformation phase of smart connected products adapted to Mekano ® can be described as follows:

Product

The initial value proposition "as is" Mekano® triangular channel is sold today as a technology product that is assembled to a grid system for supporting the facility functions on the platform which reduces the project cost on support systems with up to 30% compared to traditional solutions.

Smart Product:

A smart Mekano® triangular channel has a function that adds value through use of software, sensors and processors which enable personalization and enhanced functionality (PTC Inc., 2014). This system isn't connected to the CPS, but could give signals to the inspectors in the field, such as light or sound, an could collect data which is sampled manually on each product.

Smart connected product

The integration stage for adapting and contributing in the digital environment of O&G

With a smart connected product, the wired or wireless connectivity enables remote monitoring, control and service (PTC Inc., 2014). This also enables for data logging on product system that could be shared with the product supplier and used for product design improvement or support improvement.

Product System

Enhances the product features through the enablement of new processes and expanded product service and capabilities. (PTC Inc., 2014).The smart connected Mekano support system would enhance the reliability of the piping system, electric system or HVAC system in this context and add data for decision-making on maintenance and process parameters.

On this stage, the smart connected product is integrated with the maintenance system, and becomes a brick in the O&G offshore topside strategy for asset integrity, a "smart asset"

Ecosystem

The Mekano Smart connected support system is adding value to all the operational systems of the platform with real time data and software analytics that optimize uptime for drilling and production that rely on power and piping. Trough the connection of other systems and data, the use of combined data and AI will address process optimization and health monitoring, it will act as a total health monitoring system where Øglænd smart connected product can be utilized with respect to optimization, fault detection and correction. The data may also be utilized for other purposes.

6.3 Enables a New Business Model

Smart Connected Products can leverage new business models that goes from a product to, product-as-a-service, and where the products are measured by the performance and can be valued thereafter. With a service agreement, the supplier of the service becomes a stakeholder throughout the operational phase of the product, changing the design criteria from functionable design to reliable design. (Porter & Heppelmann, 2015 a). Since the support system merely is a support system, the measurements must be on how well it "supports" the operating system, and to what extent it is prolonging its life, or to what extent asset integrity is achieved. With a service strategy and responsibility for the assets function and fit for purpose system, a new business model can expand the scope from a "project" basis to a "life cycle basis".

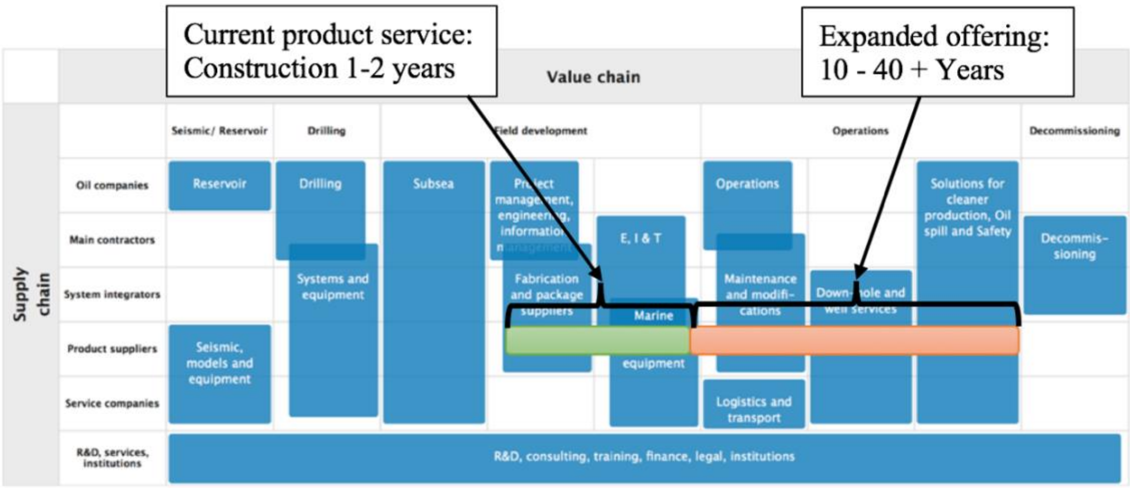


Figure 30: New Product Service (Norwegian Energy Partners, 2018)

Creating smart connected products that can adapt to the E&P operational phases and leverage its capabilities in the customers framework for IIoT devices supporting Asset Integrity of EI&T, Piping and HVAC in day to day operations. This type of business model also creates the environment for product improvement trough data feedback and analysis.

6.4 Expanded Value Proposition with Smart Connected Products

The original value proposition implies that the customer will save up to 30% on cost with multigrid and multidiscipline support systems of Mekano® channels for EI&T, Piping and HVAC systems which are fulfilling the current operations. The new value proposition will affect the asset integrity of the supported operations and a new business model will facilitate the correct responsibilities and designs for the entire life of the offshore asset, increased functionality with integrated condition monitoring system for reliable operations.

Communication with the O&G digital twin and cyber physical system will increase visibility and cognition for big data analytics in cross disciplinary systems in the eco system. The changes in responsibilities opens an opportunity for further digitalization and measurements that can track the supports design and function in relations with the environment. These data can be used for improving existing design and also facilitates the use in process optimization within the cognition level, and thereby be a basis for new designs. The ability to learn about the products performance will generate positive synergies both for the customer and for Øglænd System.

6.5 Smart Connection & Integration

A smart connected product must be supported by a digital infrastructure both for data storing, management, development and analysis. the first priority is to be able to integrate with current/future cyber physical systems and the respective digital twins, this will enable the industry use of the product sensors. The developed software must be user friendly and adaptive to the API that are being used in the industry. Although the smart connected product must be integrated with the E&P data management and IIoT platform to transform into a Smart Asset within the eco system, a framework for leveraging a new business model and analysis method must also be planned, tested and implemented to be able to add new services and use data for improved design and applications. The development of new business models may pose a challenge within the O&G industry, as they prefer to keep their data for themselves (Equinor-Informant, 2018), making leverage of a new business model challenging in this industry segment, this may however change in the future scenario as the value adding process is rooted in information sharing (Cognite-Informant, 2018) .

To be able to build upon the digital products and exploit data trough big data analytics, the base for achieving this will incorporate analytics of un structured data from the smart product, however, future data sharing may incorporate semi structured and structured information. "*Smart, connected products, cannot operate without a cloud-based technology stack*" (Porter & Heppelmann, 2015 a, p. 14). And thus incorporation of cloud based technology and the data lake concept is necessary.

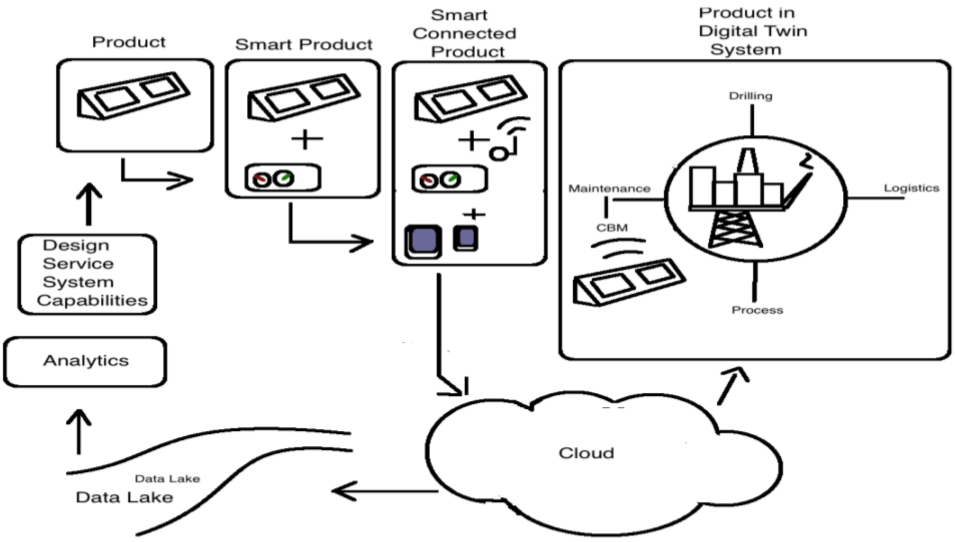


Figure 31: Looped System Development

Figure 28 illustrates a simplified closed loop model for utilization of data for improving the product, system, sensing capabilities or service related processes. the product system and system of systems has been simplified to the digital twin cyber physical system.

6.6 Organization and Business Integration

New technologies and integration of new services requires a different set of skills in addition to the contemporary skillset of the organizational stack. It will also require a higher integration between R&D and IT, as some of the new service incorporate both aspects and rely on them for further development. This is due to the new development method that is enabled trough smart connected products but also keeping the product software updated at any time."*smart, connected products requires a traditional manufacturer to build what is essentially an internal software company.*" (Porter & Heppelmann, 2015 b, p. 23). The concept of smart connected products require more than integration and coordination of IT & R&D as elaborated in section 3, the convergence of IT and OT requires better collaboration across the whole organization compared to traditional manufacturing organization. And could be achieved through three new functions. One that is taking care of data management across the entire organization, one that is using this data for product development and one that is keeping the customers updated on the development. This is illustrated in *Figure 8: Organizational Structure new functions (Porter & Heppelmann, 2015 a, p.* 27)

These functions are important if the “big data” is to be used for development of the product or service. Being able to import data from the users (O&G) , and managing the cloud storing, making it accessible for the development team to access and analyze this data, and to both create better software for condition monitoring and also to extract information on how well the product is holding up the quality throughout the lifecycle. Green Products are never completely developed, and is upgraded and updated through its functional software, this also means that the organization has to support feedback and restructure information and development processes to fit that new way of improving. (Porter & Heppelmann, 2015 b)

Development of the software and creating the data management infrastructure for handling the large amount of data could be achieved either by leveraging available competence on these systems, or by activating new collaborations within the business landscape.
Development of smart sensors for creating the smart product requires a collaboration between Øglænd System and a provider of the hardware, such as sensors, processors, connectivity, and power supply in relations to the needed specifications for the monitoring unit related to the measuring technique which impacts hardware and technology composition. The requirements from the O&G industry also has to be fulfilled in this collaboration.

The condition monitoring can be managed through Øglænd system, or by the customer (O&G). under both circumstances, the need for a software to analyze the raw data is needed, and must be either adapted to an existing software or developed in order to register the fault modes and indicate corrective measures. Accelerators in the development process can be achieved through integration and joint ventures with highly specialized technology organizations and by using their capabilities and agility the processes, software and product attributes can be combined to the value proposition. The areas that can be beneficial to assess for a collaborative cooperation can relate to new technologies that are already out there, smart connected sensors with industry specific requirements.

6.7 Sustainability

The competitiveness and sustainability of this approach is achieved through the organizational collaboration, the new competence and by leveraging this into product development of increased feedback from the customers. The results from a new approach and why they are sustainable is rooted in the smart design of the Mekano system, when data is collected on the systems performance this can both be used as a description on how fit for purpose the system composition is, and that the development process is deeply integrated in continuous feedback on monitoring capabilities as well as product capabilities.

This has the potential to affect

- The Product design
- The system composition (supports)
- The sensor system and software
- And the asset integrity (Piping/ EI&T/ HVAC)

Section 7: General Technical Considerations & Human success factors

Throughout section 6, elaboration on the possibilities and functions that can be utilized by adapting to an industry that is going through changes with digitalization is put forward.
Some potential areas and for a smart connected sensors system is elaborated, and is related to increasing the asset integrity. The possibilities for further data driven development of product, system and sensors is related to utilizing possibilities that come with investigating causality (cause & effect) from the physical uses of the product.

To leverage all the fruits from the data, organizational adaption and integration with the new strategy on improving products and services is necessary, this involves creating the right bonds with distributors, developers and experts within the fields, and also to enable the use of cloud services and data lakes that facilitate big data analytics.

Section 6 describes the foundation for developing a smart connected products. this section will elaborate some aspects concerning technical challenges and human factors related to the development process of a smart connected product, using the 5C architecture (Lee, et al., 2014) to illustrate the position Øglænd System is in relations to the O&G digitalization with respect to creating a sensor system and a smart connected product, level I combined with level II is assessed to be a smart connected product.

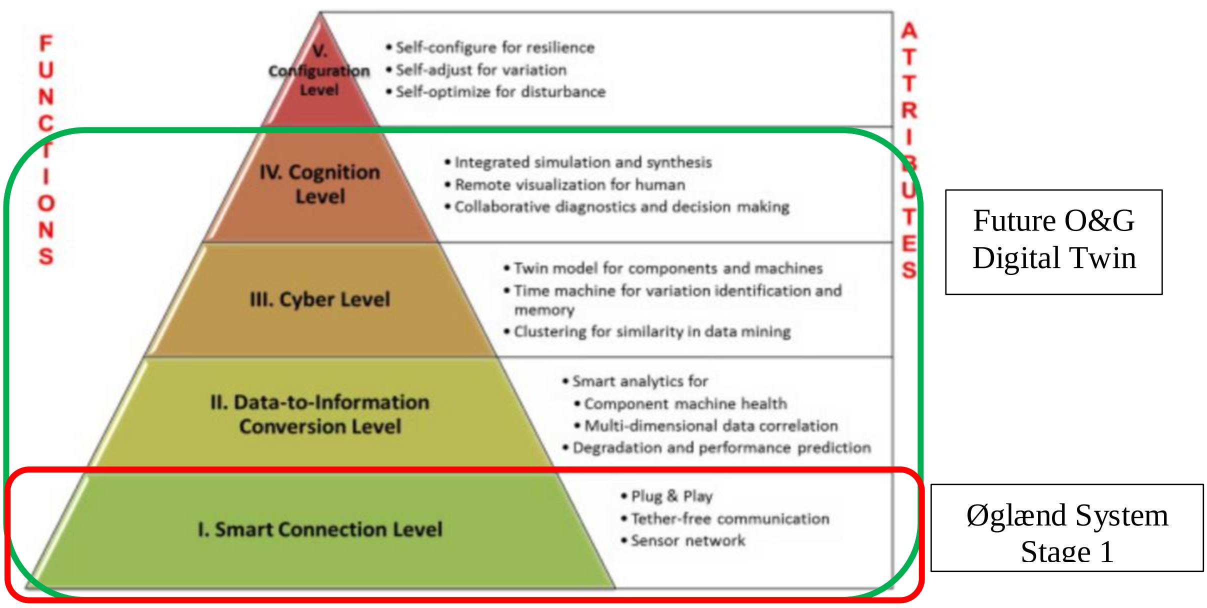


Figure 32: Øglænd Stage 1 in 5C architecture (Lee, et al., 2014)

7.1 Smart Connection level, Enabling Condition Monitoring

This level is the IIoT product development stage, and is describing some of the technical considerations in developing the sensor system together with requirements from the O&G industry. Technology development on sensors, their sizes and capabilities is evolving constantly, and reviewed in section 3, on MEMS, a size of a chip can do the work. If sensors are merged with technology such as "Edge" for signal processing in the actual component, making it a smart sensor, it can be capable of doing baseline analytics in each node (sensor) of the sensor network. Thereby it can detect irregularities from normal operation without processing signals in a centralized system and reduces the power consumption on signal transfer, this is the first stage of analytics, as elaborated in section 3, on big data analytics.
In the context of adding reliable and accurate data to the CPS, the sensor specifications has to be set with respect to the environment of the physical operations. Assessing where to place the sensor nodes is critical for detecting the right signals, and should be done in cooperation with specialists who know the field of condition monitoring, sensor selection and has experience.
"Acquiring accurate and reliable data from machines and their components is the first step in developing a Cyber-Physical System application. (Lee, et al., 2014, p. 19)

The attributes of smart sensors are described as containing microprocessors that can perform self-calibration and has standard interfaces for connecting and communicating (Wilson, 2005) which is reducing the maintenance on these components. Powering the sensor nodes can be achieved with three different methods, either by power cables, batteries or with harvesting techniques. This must be assessed with respect to power consumption and estimated lifetime of the device in operations, self-powered and battery driven devices are easier to install, and can potentially deliver enough power to sustain operation without replacement of the battery. An example on this is ABB´s self-powering device wirelessHART. To enable the monitoring process, connected devices can be achieved with at least three different methods, cabled system (Field Bus, SCADA), Wireless Connection or trough manual sampling from the product (smart product).

Condition monitoring of systems require thorough knowledge of material behavior, system physics and is widely applied to industrial applications. "*Condition Monitoring (CM), which is a term covering a range of techniques that have been developed in the past fifty years to assess the condition of systems and components. Well-known condition monitoring techniques are vibration monitoring, oil analysis, acoustic emission and thermography. These methods are widely applied in industry"* (Tinga & Loendersloot, 2014, p. 2)
For a monitoring process to be achievable, there have to be a measurable physical phenomena that can be detected by the sensor, this may be temperature, vibrations, radiation etc.
With for example structural monitoring, the use of stress/strain analysis and vibration analysis can be applied, or with monitoring of pressure vessels acoustic emission can be suitable (Drake, 1998). For vibration analytics, typical signal processing techniques are the Fast Fourier Transform (FFT), which is filtering complex waves and organizing the signal modes into a variety of amplitudes to reference the frequencies (Hunt, 1996). This can be related to failure mechanics in the system which is being measured. There is however an array of methods for signal processing signal analysis and prediction methods depending on the physics and system which is monitored. These are not elaborated in this thesis, but a general monitoring process may involve the stages shown in figure 30.

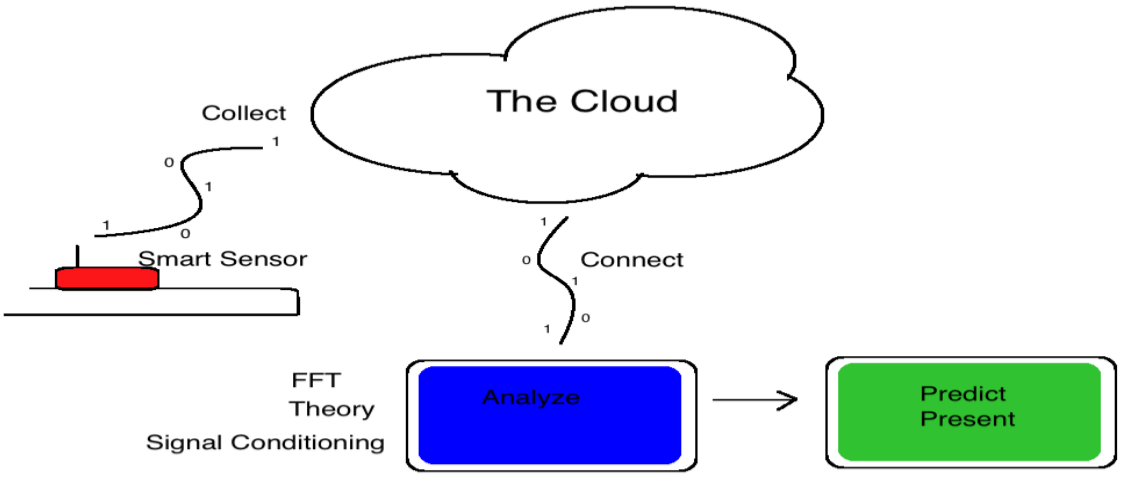


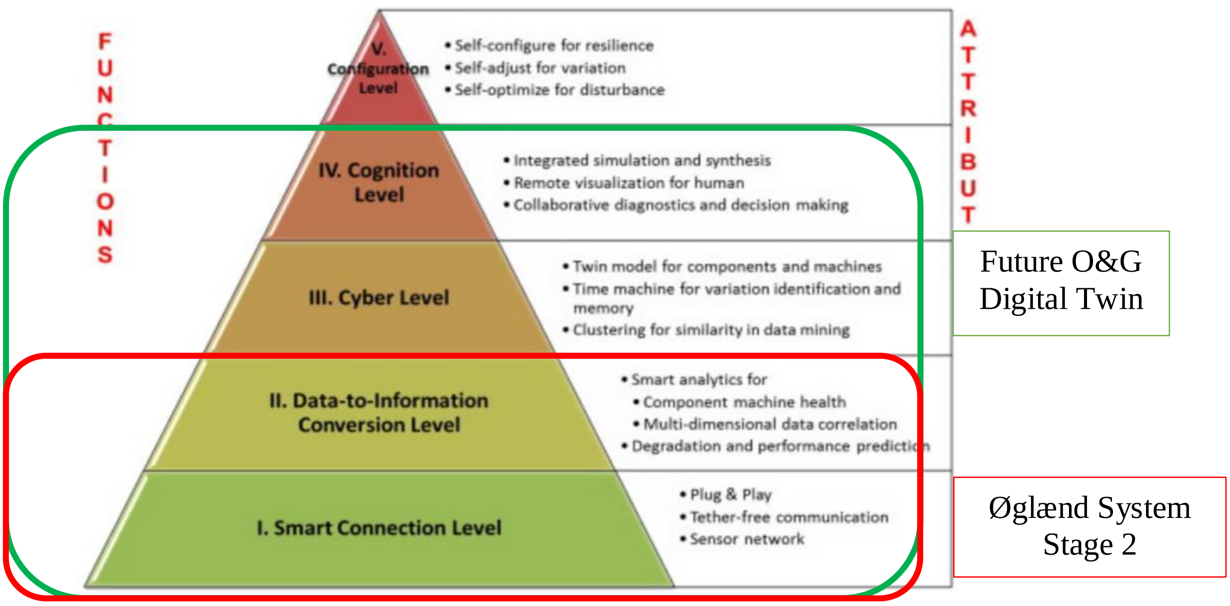
Figure 33: Simplified Condition monitoring process

The smart sensor is sending signals to the cloud when it is detecting irregularities/ or base on batching. The signals are analyzed with a software and is used together with knowledge on condition monitoring, the physical system and theory. Which is later used in the stage on predicting and presenting problems, lifetime for further actions.

7.2 Data to Information Conversion, Enabling PHM & Data Driven Development

The next stage is conducted by the O&G operator, by leveraging sensor data from Øglænd System sensor network and using the sensor readings for big data analytics and Predictive Health Monitoring (PHM) on the supported system.

For further usage by Øglænd System, this data has to be shared by the O&G operator, to leverage this data, as elaborated in chapter 6, the digital infrastructure and organizational functions has to support big data analytics, and be able to use this data for product development and, if considered, creating a new business model for selling the product as a service.



Figur 34: Øglænd System Stage 2 in 5C architecture (Lee, et al., 2014)

This stage in an industrial 4.0 concept is described by (Lee, et al., 2014) as making the machines and components self-aware with prognostics and health management algorithms. This is performed with Predictive Health Monitoring (PHM) which calculates Remaining Useful Lifetime (RUL) for systems and system components. "*PHM is a more integrated approach that aims to provide guidelines for managing the health of the system. In that way, it is a philosophy to perform Life Cycle Management, with a strong focus on the predictability (i.e. prognostics) of failures and maintenance*" (Tinga & Loendersloot, 2014, p. 3).

Using the big data to product development may need more sensors than the ones monitoring the system asset, and can require Øglænd System to incorporate multiple sensors in the smart connected product to assess other environmental factors such as temperature, strain, humidity and so forth. This information enables Øglænd System to get specific data which can be assessed together with other data for product development, either technological or trough expert analysis. O&G will likely use this data to compare data from ERP data bases, simulations, real time data and for example weather data to assess the overall health of the systems on the topside. This is how big data is making value for them, it will turn "product data into insight" This is elaborated with Figure 9: Creating Value with Data *(Porter & Heppelmann, 2015 a, p.* 8)

For Øglænd System, the technical consideration here are on what data will be shared with them, and how it can be used for strategic decisions on product development. How the data can be managed is elaborated section 6, and in section 3 on data management and data lakes, but how its exploited is however case dependent

Big data was elaborated as able to impact both product development, smart connected product development and system configuration, the data from O&G has to be managed trough preferably a Data Lake concept, which can be implemented stepwise as elaborated in section 3 in table *Tabell 1: Data Lake Integration (Hagstroem, et al., 2017, p. 3*) The first stage initiates data collection from sensors while the second stage utilizes analytics that can evaluate sensor readings and other data from the O&G environment. This enables Øglænd System to do comparison of data such as weather, humidity, vibrations, accelerations etc. using heuristics and hypothesis, these data can be transformed into value for product enhancement, for example related to corrosion resistance in location specific areas, support sizing with respect to, modal behavior, impact and vibrations in the sensor related to the supported system, and in sensor accuracy and predictability of asset integrity to mention a few. One important aspect in using heuristics and hypothesis is the contextualization of the sensor data, and in the next stage, visualization of where the products are located.

7.3 Cyber, Cognition and Configuration level, Digital Twin

This level is the new reach for O&G, and is facilitating for better collaboration between the actors in the system, it is about visualization of the products and their relations. The real time data and information on the products and systems will be used together with technologies such as AR goggles, tablets and smart phones as a tool for operational personnel seeking to keep the asset safe, up, and working properly. When problems occur, and the big data analytics or "computer researcher" (AI) can´t find solutions, humans can rely on the contextualization and use the data as support for describing faults, incidents or un-regularities related for example to weather, location and equipment. (Cognite-Informant, 2018). Process optimization can be leveraged by simulating operations and processes before the platform is built, and afterwards, the data from the simulation can be used for machine learning (Øyvann, 2018). The use of optimization can also be used in system design for the support of Piping, EI&T and HVAC using simulators and connecting it to machine learning for autonomy adjustments of design or configurations together with data on loading conditions, weather etc..

7.4 Human Factors

Implementation of new technologies can have a large influence on the organization and some of the important aspects is highlighted here. Besides developing a technical strategic method for implementing new technology in the organization, Human factors are inflicting on the implementation and development processes trough past experience, personal opinions and by influencing each other. Involving team members into a Mutual Design and Implementation (MDI) framework can be beneficial for the organization, selecting people from all levels in the organizational hierarchy to contribute to an ongoing process of change. (Mankin, 1996) Successful implementation of new technology depends on engaged technology interested people in combination with change management (Cognite-Informant, 2018)
Øglænd System is an innovative organization that has managed well trough several stages of development throughout the years, and is using advanced technology in the day to day operations. However, a new approach on digitalization with sensors and smart connected products requires new collaboration and integration between organizational functions and development of a new functional area where IT and OT is connected in a new way.
Development of sensor systems is dependent on right skilled people with experience and "know how", and it´s important to consider how to manage the change and inspire the crew to take part in this transformation. A proof of concept can be used as a motivation factor for accelerated development and optimism. And having a clear vision and strategy will guide the people to make the right decision along, as there will be plenty of challenges along the way.
A focus on flexibility and adaption is important in this phase, experimenting and failing is vital both for employees and the management to acknowledge as a part of the development.

The changes in developing smart connected products have implications for almost everyone in the organization and will require to extend or to add new functions and also to integrate existing functions to enable all the benefits from a the data driven development method.
As with all changes, they are difficult for employees who is also managing daily tasks and problem solving in parallel with the changes. (Porter & Heppelmann, 2015 b) is highlighting that this is a revolutionary method of doing development, and as with all changes and revolutions, they are difficult.

Section 8: Discussion

8.1 Discussion

The scope of this thesis revolved around how sensor technology is used within the digitalization framework that is emerging in the industry and comprises of both realized and developing technologies. A study of the digitalization technologies in the upstream O&G was performed to contextualize the uses of these digitalization visions and strategies, and finding the true objectives for this industry in the evolution to a new digital age. The focus on O&G sector is related to Øglænd System inherent position as a worldwide supplier for them, together with the long track record in this field. The challenge of this thesis was to investigate how one could transform Mekano® to a smart product using sensor technology, this required both to review information of technical aspects related to digitalization integration of different technologies and the uses of and composition of IoT, Smart Assets, and smart connected products. The combinatory effect of Smart Assets and Smart Connected Products was used to elaborate a digitalization strategy with the objective of targeting to meet O&G objectives for sensor usage related to both Øglænd System products and offshore topside asset integrity. And further on how to utilize and take advantage of the possibilities data aggregation and sharing within an industrial eco system can pose for digital and physical development of products and services.

This was done by firstly investigating the trending technologies that comprise the new digital environment and was narrowed down to focus on the technologies that are mainly related to using sensor data in factories and industrial plants, readily neglecting other technologies such as 3D printing and autonomous robots, due to the scope and context of this study.
The technologies where described by how they affect the overall systems and how they interconnect to develop intelligent industry processes and workflows,
elaborating on Architecture, CPS, digital twins and big data analysis, data management and smart assets. A further study was done on smart connected products, IIoT products and sensors to elaborate on strategies, analytics as well as technologies that support these products such as data lakes and organizational functions. The last part of this chapter goes deeper into details on how these products and systems are composed with a technical review of possibilities and challenges. In order to contextualize the industrial application of sensor technology, a review of upstream O&G was conducted to describe the emerging trends in the industry and a contextualization on the focus areas for this thesis, the offshore topsides. A further elaboration

was done on maintenance trends and the challenges that pushes them towards using digital technological solutions such as condition monitoring. In the end of this section, a review of the digitalization visions and concepts Equinor has in relations to offshore O&G operations and how a digital integrator such as Cognite is creating these digital data platforms.
The case study on Øglænd System is contextualizing their present product portfolio to the offshore O&G facilities and couple that with relations on maintenance and the systems they are supporting offshore for a short elaboration on condition monitoring and current tested methods on these to suggest one way of targeting the Smart Asset strategy.

The section covering an adaptive digitalization strategy is using the reviewed literature on smart connected products together with smart asset strategy to form a picture on these aspects in light of the O&G topside and the use of Mekano® in this context. The strategy elaborates on how Øglænd can utilize the suggested Smart Asset sensor system and the aggregated data from the eco system to impact business model and product development whit respect to the induced organizational collaboration between different functions. This was further elaborated in section 7, where the general technical aspects related to the strategy is described trough the 5C architecture as a stepwise approach to reach this vision. Technical aspects derived from the review on sensor composition was first elaborated to create the sensor system, and then the smart connected product strategy was elaborated on how the data can be used from the industrial digital system into value and impact the products and asset integrity. Also some human factor considerations are elaborated for this strategy at the end.

Some aspects related to the type of sensors that are used in the condition monitoring process, and the vast methods for doing analysis on these data are not sufficiently covered for the sake of developing the sensor system but the thesis elaborates on how to find solutions that will cover them. With respect to maintenance offshore, the field is much wider than the condition monitoring aspects and covers maintenance strategies and risk mitigation methods and other aspects that affect the choice of method and suppliers for this service. This thesis is only describing the possibilities with sensor technology within the emerging digital trends, and has delimitations on deep technical aspects related to causalities in measuring techniques, analytics and the product development strategies. The proposed solution is a vision, and the digital maturity in the industry environment must be capable of interaction and collaboration if this is going to work.

The benefit with mating a sensor system on the Mekano product or any accessory product in the purpose of condition monitoring will extend the product offering to include a digital product, in which O&G is targeting to leverage in the digital environment for improving their asset integrity. If the O&G industry is willing to share operational data related to Mekano product sensors, the data can be used for many applications regarding product and system development and have the potential to "describe" how good job the system is doing. As a recommendation, Øglænd System should evaluate the position, benefit and signals from the O&G industry. From the authors point of view, the signals on collaboration is positive from the developers while the O&G is somewhat hesitative. This may be coming along due to the added value and positive synergies it can bring. Some thoughts and consideration related to data driven development as a coming method for developing the future organization should be assessed, although the short term gain may be small, the long term gain may be positive. This approach will also deliver proof on how well the products are adapted to the function they perform, which will gain impact on development in the future. There are many challenges related to developing a condition monitoring system, and even more on data driven design optimization, these are generally described in "general technical & human success factors", "organizational changes", "data management ". The development process will be more influx than elaborated in this thesis, as other technical, organizational, political and other influencing factors will come along. There are also other considerations that has to be made related to economy, position in the industrial environment, change management and risk appetite. These are not accounted for in this thesis. A collaboration with technology leveraging organizations could ease the transformation, leveraging big data from a third party provider of sensor systems, to use for improvements.

8.2 What is Learned

Working on this thesis has given valuable insight into a fast changing industry environment that is very complex both in systems, technology and human interaction. This study has contributed to a better understanding of the vision behind the digital twin environment and the technologies that is affecting the industry revolution. A better understanding of how upstream O&G has planned to leverage this technology, and how an industry partner such as Øglænd can approach the use of sensors in this context, utilizing strategies for smart assets and smart connected products. The thesis work has also give more insight into new ways of developing products and its relation to big data analytics with the use of AI.

8.3 Main Challenges

The thesis work is not a straight forward project, as the information is contextualizing and containing more nuances as the words are written, realizing that the scope of the thesis study is important for ever coming to a final holt. The biggest challenge during the thesis was to decide how to approach a study of sensor technology and digitalization where there are so many aspects and levels to investigate that is coupled and affects each other vertically and horizontally. Studying the digitalization visions and systems while also focusing on the subordinate technology of sensors at the same time posed as a challenge to not get lost in details, while managing to retrieve enough information for further use and application. Researching upstream O&G was intriguing, but researching condition monitoring techniques on the systems related to Mekano was challenging in this context.

8.4 Further Research

Aspects and sources for further research are many, this thesis only scratches the surface of digitalization and sensor technology in the industry. As this thesis is proposing a strategy to adapt to the industry objectives and leveraging the big data, a case study on the technical and evolutionary aspects regarding this development could bring new aspects into the light, regarding both human factors in the change process, organizational changes and technically achieving the solution. With respect to big data analytics and development of products and services, a research on how to best utilize data for a eco system concept is also an intriguing path to follow.

8.5 Conclusion

The future industry will take advantage of the emerging digitalization trends which are integrating systems and utilizing big data for process optimization and industrial innovation through the entire life cycle. The use of cyber physical systems and digital twins are increasing in the upstream O&G industry, which in turn will benefit from these technologies. An important part of this picture is the contribution from Industrial IoT devices, sensor systems and smart connected products which are delivering real time data to be utilized for clever analysis within this framework. A major benefit from a digital twin environment is the ability to provide an contextualized real time picture of the asset, while also leveraging benefits from artificial intelligence for deeper insight. This improves process optimization and reliability, while also functioning as a tool for collaboration and problem solving in a more human centered way. Within an industrial eco system leveraged by these technologies, a new way of collaborating between organizations, suppliers and operators will enable a question on data sharing across the network on sensor data and the contextualized information to improve products, systems and processes in a new highly technological manner.

This thesis had a twofold challenge, first on how Øglænd can adapt to the changing industrial framework in the O&G with a smart product, and secondly on how to utilize the benefits from a sensor system within an industrial eco system. The challenge was solved using literature on strategy and vision for the future industry and reviewing technical aspects related to maturity and feasibility and challenges. This was combined to form the adaptive digitalization strategy and give technical recommendations on how to approach some of the choices that need to be accounted for in a development strategy. The thesis elaborates on how Øglænd System can approach the challenge of creating a smart Mekano® product in the context of offshore O&G targeting their industrial objective for sensor technology, and how this can be further utilized in an future industrial eco system, described trough adaptive digitalization strategy.

9.0 Bibliography

ABB, 2015. *The Energy Harvester Enabling truly autonomous temperature measurement.* [Online]
Available at: https://library.e.abb.com/public/8d1a1bc8f89949e8acb88f9c689bba97/LL_ENERGY_HARVESTER-EN_A.pdf
[Accessed 8 June 2018].
AF Gruppen, 2018. *AF Gruppen.* [Online]
Available at: https://afgruppen.no/offshore/hvac---luft--og-kjolesystemer/hvac-offshore/
[Accessed 10 May 2018].
Aggarwal, D., 2016. *Project Guru.* [Online]
Available at: https://www.projectguru.in/publications/difference-traditional-data-big-data/
[Accessed 10 June 2018].
AkerBP, 2018. *AkerBP.* [Online]
Available at: https://www.akerbp.com/en/aker-bp-forms-operations-alliance/
[Accessed 14 June 2018].
Alsen, D., Patel, M. & Shangkuan, J., 2017. *The future of connectivity: Enabling the Internet of Things,* s.l.: McKinsey & Company.
Altman, I., 2017. *Forbes.* [Online]
Available at: https://www.forbes.com/sites/ianaltman/2017/12/05/the-top-business-trends-that-will-drive-success-in-2018/#43200bad701a
[Accessed 1 Jun 2018].
Amazon, 2018. *www.amazon.com.* [Online]
Available at: https://aws.amazon.com/big-data/datalakes-and-analytics/what-is-a-data-lake/
[Accessed 6 June 2018].
Anderson, N. et al., 2017. *The Industrial Internet of Things Volume T3: Analytics Framework.* s.l.:Industrial Internet Consortium.
Andrews, E., 2015. *History.* [Online]
Available at: https://www.history.com/news/history-lists/9-things-you-may-not-know-about-the-ancient-sumerians
[Accessed 1 May 2018].
Angulo, Á., n.d. *TWI-Global.* [Online]
Available at: https://www.twi-global.com/news-events/case-studies/vibration-monitoring-and-risk-analysis-system-for-process-piping-613/
[Accessed 1 May 2018].
AVEVA Group, 2018. *Youtube.* [Online]
Available at: https://www.youtube.com/watch?v=rjWd4fZzies
[Accessed 13 June 2018].
(NOM), N. O. & Lundberg, N. H., 2018. *Store Norske Leksikon.* [Online]
Available at: https://snl.no/Statfjord
[Accessed 11 June 2018].
Baur, C. & Wee, D., 2015. *www.mckinsey.com.* [Online]
Available at: https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act
[Accessed 10 March 2018].
Berman, J. J., 2013. *Principles of Big Data : Preparing, Sharing, and Analyzing Complex Information.* s.l.:Elsevier Science & Technology.
Bloomberg, 2018. *www.bloomberg.com.* [Online]
Available at: https://www.bloomberg.com/news/sponsors/baker-hughes-a-ge-company/the-

digitalization-of-the-oil-and-gas-industry/?adv=12983&prx_t=z-ICAAAAAAFEANA
[Accessed 24 April 2018].
BRAND STUDIO , 2018. *www.aftenposten.no.* [Online]
Available at: https://www.aftenposten.no/brandstudio/feature/v/equinor/digitalisering/
[Accessed 2 June 2018].
Buchheit, M., 2018. I^2m^2-The future of industrial system monetization. In: *Journal of Inovation.* s.l.:Industrial Internet Consortium , pp. 4-20.
Bughin, J., Chui, M. & Manyika, J., 2010. *Mc Kinsey & Company.* [Online]
Available at: https://www.mckinsey.com/industries/high-tech/our-insights/clouds-big-data-and-smart-assets-ten-tech-enabled-business-trends-to-watch
[Accessed 6 March 2018].
Cearley, D., 2016. *Forbes.* [Online]
Available at: https://www.forbes.com/sites/gartnergroup/2016/10/26/gartners-top-10-strategic-technology-trends-for-2017/#37589ee2186b
[Accessed 1 Jun 2018].
Chai, Q., Singh, M., Fosselie, T. & Wiggen, F., 2011. *A Framework for Condition Management of Topsides Static Mechanical Equipment* , s.l.: Research Gate.
Chui, M. et al., 2013. *www.mckinsey.com.* [Online]
Available at:
https://www.mckinsey.com/~/media/mckinsey/industries/high%20tech/our%20insights/ten%20it%20enabled%20business%20trends%20for%20the%20decade%20ahead/mgi_it_enabled_trends_report_may%202013_v2.ashx
[Accessed 20 April 2018].
Cliomouse, 2018. *Cliomouse.* [Online]
Available at: https://www.cliomuse.com/the-imitation-game-turing-bletchley-and-the-colossus.html
[Accessed 5 May 2018].
Cognite, 2018. *Cognite.* [Online]
Available at: https://www.cognite.com
[Accessed 3 April 2018].
Cognite, 2018. *Data Liberation for a more competitive NCS.* s.l., Cognite.
Cognite-Informant, 2018. *Architect, Enterprise Integration- Cognite AS* [Interview] (3 May 2018).
Collins Dictionary, 2018. *www.collinsdictionary.com.* [Online]
Available at: https://www.collinsdictionary.com/dictionary/english/technology
[Accessed 28 March 2018].
Deloitte, 2015. *The Wall Street Journal.* [Online]
Available at: http://deloitte.wsj.com/cfo/2015/09/30/strategy-not-technology-drives-digital-transformation/
[Accessed 14 June 2018].
Deloitte, 2017. *Industry 4.0 and the digital twin Manufacturing meets its match,* s.l.: Deloitte University Press.
Deloitte, 2018. *Deloitte.* [Online]
Available at: https://www2.deloitte.com/global/en/pages/strategy/topics/business-trends.html
[Accessed 5 Jun 2018].
Devold, H., 2009. *Oil and gas production handbook, An itroduction to oil and gas production.* 2 ed. Oslo: ABB Oil and Gas.
Devold, H., 2017. *Offshore.* [Online]
Available at: https://www.offshore-mag.com/articles/print/volume-77/issue-10/digital-

solutions/digitalization-evolves-from-buzzword-to-critical-business-need.html
[Accessed 17 April 2018].
DLG-Expert report 5/2015, 2015. *Industry 4.0 – Summary report,* s.l.: Deutsche Landwirtschafts-Gesellschaft.
DNV GL, 2018. *dnvgl.com.* [Online]
Available at: https://industryoutlook.dnvgl.com/2018#Foreword
[Accessed 5 February 2018].
Drake, P., 1998. Technique selection and implementation in condition monitoring. In: A. Davies, ed. *Handbook of Condition Monitoring, Techniques and Methodology.* Systems Division, School of Engineering, University of Wales-Cardif(UWC),P.O box 688, Queens Building, Newport Road, Cardiff, CF2 3TE, UK : Chapman & Hall, pp. 483-502.
Dudley, S., 2017. *IBM.* [Online]
Available at: https://www.ibm.com/blogs/internet-of-things/iot-iiot-considerations/
[Accessed 20 May 2018].
Dunn, A., 2008. *automationmag.* [Online]
Available at: https://www.automationmag.com/features/the-father-of-invention-dick-morley-looks-back-on-the-40th-anniversary-of-the-plc.html
[Accessed 14 June 2018].
EKT Interactive, 2018. *EKT Interactive.* [Online]
Available at: https://www.ektinteractive.com/what-is-upstream/
[Accessed 10 June 2018].
Electro Chemical Society, 2018. *Electro Chemical Society.* [Online]
Available at: https://www.electrochem.org/world-of-sensors
[Accessed 5 May 2018].
England, J., 2018. *2018 outlook on oil and gas,* s.l.: Deloitte.
enviromon, 2018. *enviromon.* [Online]
Available at: https://www.enviromon.net/wireless-sensors/
[Accessed 14 June 2018].
Equinor, 2017. *Equinor.* [Online]
Available at: https://www.statoil.com/en/news/27nov2017-integrated-operations-centre.html
[Accessed 10 February 2018].
Equinor, 2017. *www.equinor.com.* [Online]
Available at: https://www.equinor.com/en/news/digitalisation-driving-value-creation.html
[Accessed 10 March 2018].
Equinor, 2018 b. *Statoil Use of Digitalisation in operations.* s.l., AVEVA World Conference, Digitalisation Getting It Right.
Equinor, 2018. *www.equinor.com.* [Online]
Available at: https://www.equinor.com/en/where-we-are/norway.html
[Accessed 3 Jun 2018].
Equinor, 2018. *www.equinor.no.* [Online]
Available at: https://www.equinor.com/en/magazine/the-art-of-failingto-succeed.html
[Accessed 8 June 2018].
Equinor-Informant, 2018. *Specialist Engineer LCI, Equinor* [Interview] (26 April 2018).
Ernst & Young, 2017. *Digitization and cyber disruption in oil and gas.* [Online]
Available at: http://www.ey.com/Publication/vwLUAssets/ey-wpc-digitization-and-cyber/$FILE/ey-wpc-digitization-and-cyber.pdf
[Accessed 30 January 2018].
Evans, B., 2017. *Forbes.* [Online]
Available at: https://www.forbes.com/sites/bobevans1/2017/11/07/the-top-5-cloud-

computing-vendors-1-microsoft-2-amazon-3-ibm-4-salesforce-5-sap/#71d8c4726f2e
[Accessed 29 May 2018].
Flamm, K., 2017. *Measuring Moore's Law: Evidence from Price, Cost, and Quality Indexes,* s.l.: University of Texas at Austin.
Galetto, M., 2018. *A Definition of Data Management.* [Online]
Available at: https://www.ngdata.com/what-is-data-management/
[Accessed 29 May 2018].
Gandhi, P., Khanna, S. & Ramaswamy, S., 2016. *HBR.* [Online]
Available at: https://hbr.org/2016/04/a-chart-that-shows-which-industries-are-the-most-digital-and-why
[Accessed 16 April 2018].
Gartner, 2018. *Creating A Reliable Digital Twin,* s.l.: Gartner/AVEVA.
Gartner, 2018. *Gartner.* [Online]
Available at: https://www.gartner.com/it-glossary/digitalization/
[Accessed 5 May 2018].
Gartner, 2018. *Gartner.* [Online]
Available at: https://www.gartner.com/it-glossary/digitalization/
[Accessed 16 April 2018b].
GE Digital, 2018. *General Electric.* [Online]
Available at: https://www.ge.com/digital/blog/everything-you-need-know-about-industrial-internet-things
[Accessed 25 May 2018].
GE Digital, 2018. *General Electric.* [Online]
Available at: https://www.ge.com/digital/blog/3-major-digital-industrial-trends-watch-2018
[Accessed 5 Jun 2018].
GE Digital, 2018. *What is Edge Computing?.* [Online]
Available at: https://www.ge.com/digital/blog/what-edge-computing
[Accessed 6 June 2018].
Giorgio Biscardini, R. M. D. B. a. A. d. M., 2017. *2017 Oil and Gas Trends & Adjusting business models to a period of recovery,* s.l.: PWC.
Goeden, M., 2017. *www.learningindustry.com.* [Online]
Available at: https://elearningindustry.com/using-virtual-reality-to-train-employees-4-industries
[Accessed 5 June 2018].
GTAI, 2018. *Germany Trade and Invest.* [Online]
Available at: https://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Industrie-4-0/Industrie-4-0/industrie-4-0-what-is-it.html
[Accessed 10 June 2018].
Hagstroem, M., Roggendorf, M., Saleh, T. & Sharma, J., 2017. *A smarter way to jump into data lakes,* s.l.: McKinsey & Company.
Hunt, T. M., 1996. *Condition monitoring of Mechanical and Hydraulic Plant, a consise introduction and guide.* 1 ed. s.l.:Chapman & Hall.
IBM, 2018. *IBM.* [Online]
Available at: https://www.ibm.com/cloud/learn/what-is-cloud-computing
[Accessed 29 May 2018].
Ileby, M. & Knutsen, E., 2017. Data-driven remote condition monitoring optimizes o shore maintenance, reduces costs. *World Oil,* Volume 2017, pp. 60-62.
Inductiveautomation, 2018. *Inductiveautomation.* [Online]
Available at: https://inductiveautomation.com/what-is-scada
[Accessed 2 April 2018].

I-Scoop, 2016. *I-Scoop.* [Online]
Available at: https://www.i-scoop.eu/industry-4-0/
[Accessed 28 February 2018].
I-Scoop, 2016. *I-Scoop.* [Online]
Available at: https://www.i-scoop.eu/industry-4-0/
[Accessed 28 February 2018].
I-Scoop, 2018 b. *I-Scoop.* [Online]
Available at: https://www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/digital-twins/
[Accessed 1 June 2018].
Joshi, R., Didier, P., Jimenez, J. & Carey, T., 2018. *The Industrial Internet of Things Volume G5: Connectivity Framework.* s.l.:Industrial Internet Consortium .
Khine, P. P. & Wang, Z. S., 2018. *Data Lake: a new ideology in big data era,* s.l.: ITM Web of Conferences.
Klingenberg, C., 2017. *Industry 4.0: what makes it a revolution?*, s.l.: Research Gate.
Kuphaldt, T. R., 2009. Vol III Semiconductors Fifth Edition. In: *Lessons in Electric Circuits.* s.l.:Design Science License.
Lasi, H. et al., 2014. Industry 4.0. In: T. I. J. o. WIRTSCHAFTSINFORMATIK, ed. *Business & Information Systems Engineering Vol 6.* s.l.:Springer, pp. 239-242.
Lee, J., Bagheri, B. & Kao, H.-A., 2014. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, 10 December, pp. 18-23.
Littlefield, M., 2016. *LNS Research.* [Online]
Available at: http://blog.lnsresearch.com/5-ways-smart-connected-products-will-transform-quality-management
[Accessed 1 June 2018].
Mankin, D. &. C. S. &. B. T., 1996. Organizations without boundaries. In: *Teams and technology: Fulfilling the promise of the new organization.* s.l.:Harvard Business School Press, pp. 3-16.
Manyika, J. et al., 2011. *Big data: The next frontier for innovation, competition, and productivity,* s.l.: McKinsey Global Institute.
Manyika, J. et al., 2015. *McKinsey & Company.* [Online]
Available at: https://www.mckinsey.com/industries/high-tech/our-insights/digital-america-a-tale-of-the-haves-and-have-mores
[Accessed 16 April 2018].
Markovsky, G., 2018. *Enclypædia Britannica.* [Online]
Available at: https://www.britannica.com/biography/Claude-Shannon
[Accessed 5 May 2018].
Marr, B., 2017. *Forbes.* [Online]
Available at: https://www.forbes.com/sites/bernardmarr/2017/03/06/what-is-digital-twin-technology-and-why-is-it-so-important/#5e9c10ff2e2a
[Accessed 1 June 2018].
matthews, K., 2017. *www.bigdata-madesimple.com.* [Online]
Available at: http://bigdata-madesimple.com/5-big-data-trends-expected-to-influence-artificial-intelligence-in-2018/
[Accessed 6 June 2018].
McAllister, J., 2017. *Teska Labs.* [Online]
Available at: https://www.teskalabs.com/blog/industrial-iot-it-ot-convergence
[Accessed 14 June 2018].

Mc Kinsey & Company, n.d. *Mc Kinsey & Company*. [Online]
Available at: https://www.mckinsey.com/featured-insights/internet-of-things/how-we-help-clients
McKeon, A., 2018. [Online]
Available at: https://searcherp.techtarget.com/feature/Where-the-industrial-IoT-vulnerabilities-lurk-in-your-plant
[Accessed 14 June 2018].
Melanson, A., 2015. *www.aethon.com.* [Online]
Available at: http://www.aethon.com/industry-4-0-means-manufacturers/
[Accessed 24 April 2018].
MEMSnet, 2018. *memsnet.* [Online]
Available at: http://www.memsnet.org/mems/what_is.html
[Accessed 20 March 2018].
Meola, A., 2016. *Business Insider.* [Online]
Available at: http://www.businessinsider.com/internet-of-things-cloud-computing-2016-10?r=US&IR=T&IR=T
[Accessed 1 June 2018].
Nichols, K. & Sprague, C., 2011. Getting ahead in the cloud. *Mc Kinsey on Governement, Number 7*, pp. 50-57.
Norwegian Energy Partners, 2018. *Norwegian Energy Partners.* [Online]
Available at: https://www.norwep.com/Partners/Oil-Gas-Upstream
[Accessed 10 May 2018].
Novotek, 2018. *www.novotek.com.* [Online]
Available at: https://www.novotek.com/no/l-sninger/cyber-security-for-produksjons-og-prosessnettverk/det-er-fundamentale-forskjeller-mellom-it-og-ot-sikkerhet
[Accessed 16 February 2018].
Odland, P. J., 2015 a. *OFF500 Offshore field development, Tension leg platforms and Deep draft floaters,* s.l.: University of Stavanger.
Odland, P. J., 2015 b. *OFF515 Offshore field devellopment, Fixed platforms,* s.l.: University of Stavanger, Department of Mechanical and Structural Engineering and Materials Science.
Oglaend System, 2018 g. *Oglaend System.* [Online]
Available at: https://www.oglaend-system.com/products/support/mekano-support-system/
[Accessed 10 June 2018].
Oil And Gas People, 2018. *Oilandgaspeople.com.* [Online]
Available at: https://www.oilandgaspeople.com/news/16032/shell-sweeps-nine-of-19-blocks-awarded-in-mexico-oil-auction/
[Accessed 5 Februar 2018].
Ostrower, D., 2018. *Smart Connected Products: Killing Industries, Boosting Innovation.* [Online]
Available at: https://www.wired.com/insights/2014/11/smart-connected-products/
[Accessed 6 June 2018].
Pasero, D., 2018. *Powering sensor nodes for industrial IoT.* [Online]
Available at: https://www.powerelectronicsnews.com/technology/powering-sensor-nodes-for-industrial-iot
[Accessed 8 June 2018].
Pasero, D., 2018. *Powering sensor nodes for industrial IoT.* [Online]
Available at: https://www.powerelectronicsnews.com/technology/powering-sensor-nodes-for-industrial-iot
[Accessed 8 June 2018].

Platform industrie 4.0, 2016. *Platform industrie 4.0.* [Online]
Available at: https://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/rami40-an-introduction.pdf?__blob=publicationFile&v=7
[Accessed 1 June 2018].
Porter, M. & Heppelmann, J., 2015 b. *Harvard Business Review.* [Online]
Available at: http://lp.servicemax.com/rs/020-PCR-876/images/HBR-Connected-Products-Summary.pdf
[Accessed 29 March 2018].
Porter, M. & Heppelmann, J. E., 2015 a. *Harvard Business Review.* [Online]
Available at: https://hbr.org/2015/10/how-smart-connected-products-are-transforming-companies
[Accessed 29 March 2018].
PTC Inc., 2014. *Smart Connected Products.* [Online]
Available at:
https://www.ptc.com/ko/~/media/Files/PDFs/IoT/PTC_Smart_Connected_Products_eBook.pdf?la=en
[Accessed 23 May 2018].
PTC, 2018. *www.ptc.com.* [Online]
Available at: https://www.ptc.com/en/products/iot/smart-connected-products
[Accessed 20 February 2018].
Ravnestad, G., Panesar, S. S. & Kayrbekova, D. M. T., 2017. *Improving Periodic Preventive Maintenance Strategies Using Condition Monitoring Data,* P.O. Box 8040, 4068 Stavanger, Norway: Apply Sørco & University of Stavanger.
Raza, J. & Liyanage, J., 2007. Technical integrity and performance optimization for enhanced reliability in "Smart Assets"; case of a North Sea oil and gas production facility. In: T. A. &. J. E. Vinnem, ed. *Risk Reliability and Societal Safety Volume 3: Application Topics.* P.O. Box 447,2300 AK Leiden: Taylor Francis, pp. 2509-2516.
Rüßmann, M. et al., 2015. *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries,* , s.l.: The Bostin Consulting Group..
Reinecke, E. & Gibson, S., 2018. *Dimension data.* [Online]
Available at: https://www2.dimensiondata.com/it-trends/digital-business-2018
[Accessed 1 Jun 2018].
Rescher, N., 2013. *On Leibnitz.* Pittsburg, Pa 15260: University of Pittsburg Press.
Ronk, J., 2014. *jeremyronk.wordpress.com.* [Online]
Available at: https://jeremyronk.wordpress.com/2014/09/01/structured-semi-structured-and-unstructured-data/
[Accessed 14 June 2018].
Sandeepan, C. & Kavita, D., 2015. *Mechanical Vibration Analysis Of HVAC system and Its Optimization Techniques,* s.l.: Advance Research in Electrical and Electronic Engineering .
S. Z. Kamal, B. et al., 2016. *IT and OT Convergence - Opportunities and Challenges,* s.l.: Society of Petroleum Engineers.
S.Ravi, S.KarthikRaj, D, S. & R.Kishore, 2016. *Pipeline Monitoring Using Vibroacoustic Sensing – A Review,* s.l.: International Research Journal of Engineering and Technology (IRJET).
Schwab, K., 2018. *World Economic Forum.* [Online]
Available at: https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab
[Accessed 15 March 2018].

Serpanos, D. & Wolf, M., 2018. *Internet of Things (IOT) Systems, Architectures, Algorithms, Methodologies.* s.l.:Springer.
Shannon, C. E., 1948. *A Mathematical Theory of Communication,* s.l.: Harvard Mathematical Department, Reprinted with corrections from The Bell System Technical Journal, Vol. 27, pp. 379–423, 623–656.
Sherif, N., 2017. *The four Vs of big data and the questions you should be asking.* [Online]
Available at: https://www.computerdealernews.com/blog/the-four-vs-of-big-data-and-the-questions-you-should-be-asking/53005
[Accessed 5 June 2018].
smalltechconsulting, 2018. *smalltechconsulting.* [Online]
Available at: http://www.smalltechconsulting.com/mems-nanotechnology.shtml
[Accessed 1 April 2018].
Southwest Center for Microsystems Education (SCME), 2011. *MEMS Application Overview,* 800 Bradbury Drive SE, Suite 235Albuquerque, NM 87106-4346: Southwest Center for Microsystems Education and The Regents of the University of New Mexico..
Tasintu, P., 2013. *Vibration analysis of offshore piping systems under maintenance and modification projects.,* s.l.: University Of Stavanger.
Technical-Advisor, 2018. *Øglænd System* [Interview] (24 May 2018).
Tinga, T. & Loendersloot, R., 2014. *Aligning PHM, SHM and CBM by understanding the physical system failure behaviour,* s.l.: Research gate.
Verdensklassen,, 2018. *Verdensklassen, Norsk olje & Gass.* [Online]
Available at: http://www.verdensklasse.no/fakta/?id=759&t=Utbygging-og-produksjon
[Accessed 10 June 2018].
Westerman, G., 2017. *Your Company Doesn´t need a Digital Strategy,* s.l.: Massachusetts Institute of Technology .
Wilson, J. S., 2005. *Sensor Technology Handbook.* 1. ed. s.l.:Elsevier .
www.optasense.com, 2018. *www.optasense.com.* [Online]
Available at: http://www.optasense.com/wp-content/uploads/2017/05/Condition-Monitoring-for-Power-Cables_Case-Study_A4-Digital.pdf
[Accessed 2 May 2018].
Øglænd System, 2018 b. *Øglænd System.* [Online]
Available at: https://www.oglaend-system.com/solutions/engineering-support/
[Accessed 9 February 2018].
Øglænd System, 2018 c. *Øglænd System.* [Online]
Available at: https://www.oglaend-system.com/solutions/project-development/
[Accessed 12 February 2018].
Øglænd System, 2018 d. *Øglænd System.* [Online]
Available at: https://www.oglaend-system.com/products/support/mekano-support-system/
[Accessed 13 February 2018].
Øglænd System, 2018 e. *Øglænd System.* [Online]
Available at: https://www.oglaend-system.com/products/accessories/hvac-clamps-and-straps/circular-ducting/insulated-hvac-clamphvac-clamp-for-insulated-ducting-a-h-hc-id-250-pg-article27208-47217.html
[Accessed 13 February 2018].
Øglænd System, 2018 f. *Øglænd System.* [Online]
Available at: https://www.oglaend-system.com/products/accessories/pipe-clamps-shoes-and-accessories/
[Accessed 13 February 2018].

Øglænd System, 2018. *Øglænd System*. [Online]
Available at: https://www.oglaend-system.com/historie/?noredirect=true
[Accessed 23 February 2018].
Øyvann, S., 2018. Alt fra dokumentasjon til autonome operasjoner. *Computerworld-Sårbarheten Vokser*, 36(2, Uke9), pp. 30-32.