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Preface

This master's thesis is written as part of an Executive MBA at the University of Stavanger. The degree was completed from 2016 to 2019 while combining the studies with my fulltime job as an engineer and private life. At times the metaphorical "light at the end of the tunnel" has seemed dim and distant, but it has also been a rewarding journey which I would not be without. The six courses in topics related to leadership, economics and strategy have all been made interesting by knowledgeable and enthusiastic professors and guest lecturers, inspiring both learning and reflection. But just as important, the diverse personal and professional backgrounds of my fellow students have led to numerous engaging discussions, which I strongly believe have taken our learning to the "next level".

I want to extend a big thanks to my supervisor, Håkon Brydøy, for his support and guidance. To my colleagues in Aker Solutions for their time and invaluable input. But first and foremost, to my partner for her patience and to our parents for helping to babysit. Thank you all!

Oslo, 30.04.2019

Anders Hanevold

Abstract

Object-orientation refers to the holistic description of a component (object) as a single entity in a single database. By modeling real world entities in their true to life representation and using the object model as a data platform, one can create a common understanding and communicate about complex systems more efficiently. Through literary research and interviews with key personnel in Aker Solutions ASA, this study revealed that the company's subsea organization has a document-oriented approach to project execution, where engineering deliverables are planned and measured primarily based on the status for documents included in the master document list (MDL). Information contained in the MDL documents collectively captures the life cycle information (LCI) required by operators to install, operate and service the supplied hardware. Dividing the information in documents allows for a manageable way to create progress plans, split the workload, execute document reviews, revision control and monitor the engineering progress. However, the document-oriented approach also has several challenges. One being that the document contained information cannot be automatically extracted and exchanged, which results in a static information library. In addition to the challenges related to the document-oriented approach, Subsea also has challenges associated with its IT system architecture. Primarily that they do not have a unified software platform for system and application engineering. Instead they are relying on multiple stand-alone software solutions, which inhibits data consistency, information exchange and reuse of engineering. The goal is to solve these challenges by implementing object-orientation in the subsea project execution model.

It exists several software solutions based on object-orientation, but COMOS is the preferred software platform for Aker Solutions. This is partially due to historical decisions which have resulted in the company's existing IT architecture. Naturally there are challenges with implementing object-orientation that need to be addressed, but this thesis concludes that object-orientation methodology has the potential to significantly improve productivity and quality for subsea project execution, if implemented correctly and used in its full capacity.

Keywords: Operational excellence, object-orientation, digitalization, project control, collaborative engineering, knowledge management, standardization and reuse.

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Abbreviations

3D	Three-dimensional
ASP	Advanced subsea production
ASTM	American Society for Testing and Materials
CEO	Chief executive officer
COMOS	Component object server
E3D	Everything3D (latest SW generation of PDMS)
EI&C	Electrical instrument & control
EN	European Standard
EPC	Engineering, procurement & construction
ERP	Enterprise resource management
EU	European Union
FBD	Function block diagram
FEED	Front-end engineering & design
FPSO	Floating production, storage & offloading
GDPR	General Data Protection Regulations
IFC	Issued for construction
IP	Intellectual property
ISO	International Organization for Standardization
IT	Information technology
LCI	Lifecycle information
MDL	Master document list
MMO	Maintenance, Modifications and Operations
NPV	Net present value
OSE	Oslo Stock Exchange
PDMS	Plant Design Management System
PEM	Project execution model
PFD	Process flow diagram
P&ID	Piping & instrumentation diagrams
PLC	Programmable logic controllers
RFID	Radio-frequency identification
SAS	Safety automation system
SCD	System control diagram
SPS	Subsea production system
VR	Virtual reality
WBS	Work breakdown structure

Table 1 – Abbreviations

Terminology

Best practice	Commercial or professional procedures that are accepted or prescribed as being correct or most effective
Brownfield	Projects with constraints imposed by prior work
Concurrent design process	Simultaneously completing design and manufacturing stages
Digitalization	The process of converting information into a digital (i.e. computer-readable) format
Digital twin	Digital replica of a physical asset
Greenfield	Projects without constraints imposed by prior work
Holistic	The idea that systems (physical, biological, chemical, social, economic, mental, linguistic) and their properties should be viewed as wholes, not just as a collection of its parts
Metadata	A set of data that describes and gives information about other data
Paradigm change	A fundamental change in basic concepts and practices, where the usual way of thinking about or doing something is replaced by a new and different way
S-curve	A project management tool that tracks progress over time and allows for a quick visual to determine project status
Unified data platform	A set of technologies that work together to move data throughout an organization
Work breakdown structure	A hierarchical breakdown of project deliverables

Table 2 - Terminology

1 Introduction

In today's challenging market, contractors in the oil and gas industry are under pressure to offer more cost-efficient products and services. One key enabler to reduce cost is achieving operational excellence and companies are leaving no stone unturned in their quest to optimize organizational setup and project execution. Historically, the oil and gas business has not been early adopters of new technology (Thakur, 2011), but the market downturn that started in 2014 triggered an industrywide surge of digitalization initiatives. To put it simply, if you want to do more with less you have to work smarter.

This paper aims to investigate if object-oriented methodology, through the COMOS platform, can contribute to achieving operational excellence in Aker Solutions ASA's (hereby referred to as Aker Solutions) subsea business segment. The goal is to find precedence for, or against, implementing COMOS and object-orientation, by interviewing stakeholders and decisionmakers in the Aker Solutions organization and compare the findings with academic research on the subject. The purpose of the paper is, however, not to quantify cost of implementation or potential cost savings. Performing a net present value (NPV) analysis is an important part of a major decision process, but such a complicated analysis would warrant its own paper. It is neither the purpose to compare different software solutions that are based on object-oriented methodology. This thesis instead focuses on the process aspect by identifying and discussing potential opportunities and challenges. Large software platforms require extensive infrastructure and support organizations, so there are obvious benefits by standardizing processes and tools. For topside Greenfield projects, Aker Solutions have used COMOS integrally since 2006 and the software platform has also been used on some subsea projects, although in a limited capacity. IT infrastructure and support organization are therefore already in place, making COMOS the preferred platform for Aker Solutions. Furthermore, to capitalize on synergies and improve resource pool flexibility between business units is also a strategic ambition in Aker Solutions.

Research for this thesis has uncovered several articles on the topic of object orientation, the COMOS software platform, and how the methodology and the software can be used to improve project execution. However, little literature has been found about using object-orientation and COMOS in the subsea oil and gas industry. The research for this paper has been done in cooperation with Aker Solutions, focusing on this company's processes, working methods and IT system architecture. Limiting the research to a single company can potentially impact the broader relevance of the study, but by doing so it has been possible to gain better insight in the organizational structures and processes, in addition to having access to key personnel. Furthermore, the product offerings and working methods in the subsea industry are very similar, so it is presumed that challenges seen in Aker Solutions are equally relevant also in comparable companies. COMOS might not be the best suited software solution for other companies, due to differences in IT system architecture, but it is believed that the positive effects of the object-oriented methodology are equally applicable.

1.1 Background

In December 2010 Aker Solutions was awarded the EPC contract for the Åsgard Subsea Compression project by Norwegian Operator then known as Statoil, now Equinor ("Åsgard – Solving One of Subsea's Biggest Challenges", n.d.). This was the first subsea project where dry gas compressors for hydrocarbons were to be installed on the seabed, instead of on topside platforms/vessels or onshore. Moving processing equipment such as coolers, separators, pumps and compressors subsea meant a high level of process engineering complexity, which is unusual for traditional subsea projects. In addition to the subsea compression station that were to be delivered, the Åsgard project scope also included a topside processing module that would be installed on the *"Åsgard A"* FPSO. At the time, Aker Solutions was legally structured with separate business units and it was decided to execute the Åsgard project as a joint venture between Subsea, Greenfield and the Egersund fabrication yard. Drawing on experience from Greenfield it was decided early in the project to use COMOS, a life cycle engineering and plant asset management software by Siemens AG, for the project execution. COMOS had been used by Greenfield, where complex process engineering is the norm, since 2006, but the software platform had not previously been used for subsea projects. See section 1.3 for more information about the COMOS software platform.

After five years of project execution, installation, commissioning, and one year of production, Equinor reported in September 2016 that the Åsgard Subsea Compression Station had maintained a system regularity of close to 100% throughout its first year of operation ("Statoil celebrates first anniversary of Asgard subsea gas compression system", n.d.). There were many success factors for this achievement, but the highly successful uptime could not have been made possible without well executed process and system engineering. However, the number of engineering hours was high and while Equinor reported successful operation of the Åsgard facility, the oil and gas industry was in the middle of a critical market downturn due to overproduction. In 2013 and 2014 the Brent crude oil price had fluctuated between $100-120 USD per barrel, but in June 2014 the price started to trend downwards, continuing to fall until bottoming out at $28 USD per barrel in January 2016. Many companies had started addressing the industrywide cost inflation that had manifested already prior to the oil price collapse, but with oil prices below $30 USD, improving cost efficiency was now a matter of survival for operators and contractors alike.

Operational excellence has always been on the agenda in Aker Solutions, but it can be argued that growing operational capacity had taken priority in the years before the market collapse. Regardless, the times were changing and in November 2015 Aker Solutions launched its improvement program called *#thejourney,* based on LEAN methodology (Womack & Jones, 1996). The initial goal was to improve cost efficiency by minimum 30% by the end of 2017, compared to 2015 figures. This goal was reached ahead of schedule and extended to be a minimum of 5% additional cost-efficiency improvement per year by the end of 2021 (Aker Solutions, 2018). To continue improving project execution and to capitalize on synergies between Subsea and Greenfield, executive management requested for a business case assessment to be performed in 2018, with the purpose of evaluating an implementation of COMOS in Subsea's project execution toolbox. While most of the company's subsea projects are product oriented in nature, it is a clear ambition to win more work in the emerging market of advanced subsea processing and boosting. In March 2019 FEED work was kicked off for Jansz subsea compression project ("Aker Solutions Wins FEED Contract for Subsea Compression System", 2019), and Åsgard Subsea Compression second phase studies are currently ongoing, in addition to several concept studies. While the Åsgard project was a success, both in terms of technology development and increased field recovery, cost of engineering can be a potential showstopper for future projects.

This thesis was started in August 2018 with support from Morten Bentzon, vice president for PEM and responsible for the business case evaluation. In late September 2018 it was decided by executive management to proceed with the implementation initiative, as a step towards achieving more efficient projects execution in Subsea. However, COMOS is a major change initiative which is assumed will take years to fully roll out, so a critical review of the possibilities and challenges related to implementing object-oriented methodology is still thought to be valuable.

1.2 About Aker Solutions

Aker Solutions ASA is a global oil service company that is based in Oslo and publicly traded on Oslo Stock Exchange (OSE). The company is the result of a merger in 2002 between the two rivaling companies that started as Aker Mekaniske Verksted, founded in 1841, and Kvaerner Brug, founded in 1853. After the merger in 2002 the company took the name Aker Kvaerner.

In the early days both Aker and Kvaerner's main businesses were focused on shipbuilding and manufacturing components for machinery. Over the years both companies have been engaged in a wide variety of businesses, such as hydropower, fisheries, paper and pulp, to mention a few. But mechanical and marine engineering soon became their core businesses. When oil companies discovered oil and gas in the North Sea in the 1960's, Aker Mekaniske Verksted started developing its own rigs and in 1967 the Aker built rig "Ocean Viking" was used to discover Norway's first oil field, Ekofisk. In April 2008 the company announced that it would divest its paper and pulp, and shipbuilding business to focus on the oil and gas industry under the name Aker Solutions ("History and Heritage", n.d.).

Per April 2019 Aker Solutions has approximately 15.000 employees working from 53 different locations in 20 countries, and the company is structured with five delivery centers, being: Customer Management, Front End, Products, Greenfield Projects and Brownfield Projects.

The company's key figures are:

ORDERS AND RESULTS		**2018**	**2017**	**2016**
Order backlog	NOK mill	35,148	34,581	31,188
Order intake	NOK mill	25,421	23,553	17,004
Revenue	NOK mill	25,232	22,461	25,557
EBITDA	NOK mill	1,810	1,519	1,929
EBITDA margin	Percent	7.2	6.8	7.5
EBIT	NOK mill	1,049	571	687
EBIT margin	Percent	4.2	2.5	2.7
Net profit	NOK mill	554	239	152

Table 3 - Financial key figures (Aker Solutions, 2019)

1.3 About COMOS

COMOS is an object-oriented software platform for life cycle engineering and plant asset management. The software was originally developed by innotec GmbH and the first version was released in 1996. But in October 2008 the company was acquired, and it is now under Siemens AG ownership ("Antitrust authorities approve Siemens acquisition of innotec", 2008). COMOS is currently in its 10th generation with version 10.2 released in April 2016 ("New Comos Version 10.2 for faster, more efficient engineering", 2016). The software's slogan is "*COMOS – Making data work. Better quality decision-making through the plant's entire lifecycle*" ("COMOS – Making Data Work", n.d.).

Ensuring optimal coordination and workflow between involved disciplines and departments are important for efficient plant design and management, both to minimize design cost and time, and to maximize equipment uptime. As a software platform, COMOS' purpose is to facilitate efficient communication and execution in all the plant's lifecycle phases by providing plant design engineers, plant operators and management with a continuous date flow which meet each user's requirements. This is done by using a unified data platform to model the plant, based on an object-oriented methodology, where components are described holistically and displayed graphically in their true to life representation. Relevant data such as lists, manuals, data sheets and other documentation are linked to the component, and together the information forms a single unit in the database – the object. COMOS stores the complete plant information in a central database so that all sites, disciplines and departments have access to the same data. Furthermore, all objects can be processed bidirectional by multiple users and changes are updated in real time, meaning that objects can be studied and further developed from a functional and interdisciplinary perspective, regardless of locations and time zones. The COMOS platform consist of a centralized data server and the four primary modules COMOS Process, COMOS Automation, COMOS Operations and COMOS Lifecycle [ref. Figure 1] ("COMOS at a glance", n.d.). For descriptions of each of the four COMOS modules, see APPENDIX A – COMOS.

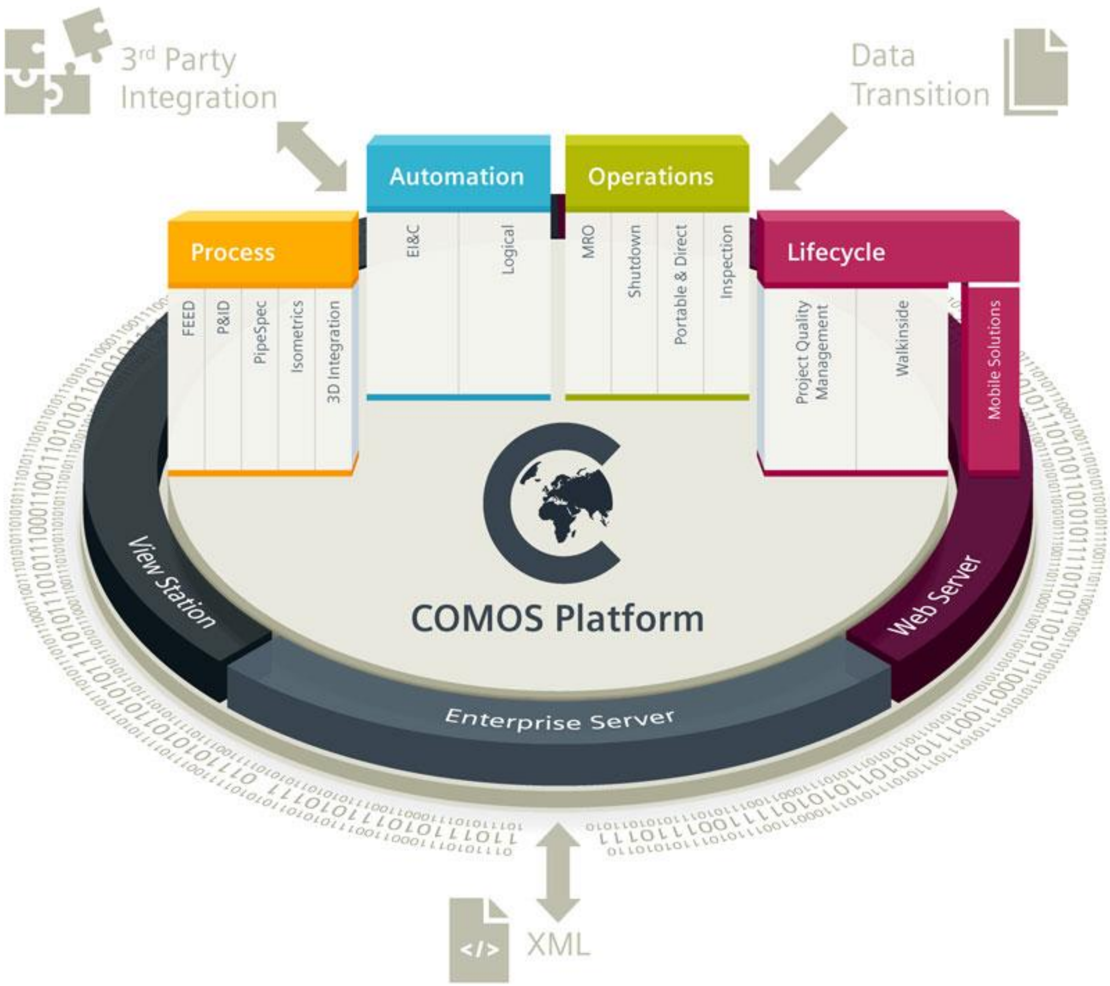

Figure 1 – COMOS Platform

1.4 Thesis research scope

The purpose of this study is to evaluate if object orientation methodology, through COMOS, can contribute to operational excellence for subsea projects. The methodology and software can, however, be used in many ways and each way impacts organization and project performance differently. Companies competing in the same market will normally share many of the same challenges, being linked to external conditions such as geographical location, market regulation, political environment, international standards, client requirements and technological challenges, but companies will also have individual internal challenges. To answer the research question, this study has reviewed publications relevant to the topic and interviewed six senior managers in the Aker Solutions organization. The interviewed candidates all have knowledge of the COMOS initiative and they either have strategic, project owner, department and/or engineering management responsibilities. The purpose of the interviews has been to clarify what the candidates regards as the biggest challenges with today’s project execution model and how object orientation can contribute towards operational excellence. The intention behind the research population selection was to map both the strategic ambitions of senior/executive management, and to identify the operational challenges as seen by engineering/department managers. By defining operational excellence as doing all the right things and doing them optimally efficiently, it can be argued that operational excellence is a moving target which can never be reached, but which is meant to inspire continuous improvement. It therefore does not exist any *one* solution for operational excellence, but in the context of subsea project execution, this paper will discuss four topics which have been identified to be important for improving operational efficiency. The four topics are:

- Digitalization
- Collaborative engineering
- Project control
- Knowledge management and reuse

This thesis will not try to quantify cost of implementation or potential cost savings, nor will it compare alternative software platforms for object-oriented engineering.

2 Theory

This chapter will introduce the theory and history behind object-oriented methodology, but theory and research that is relevant for the four identified topics are included in the discussion section [ref. chapter 5].

2.1 Object-oriented project management

Object-oriented project management methodology was conceived in academia and research settings for software development in the 1960's. During the 1970's there was done extensive studies on the field and in the 1980's the method was gaining acceptance for commercial and industrial use (Kanabar et al., 1996; Pullan et al., 2012). When developing software, engineers are often faced with complex system structures that the software shall integrate with. Due to the complexity and large scope of work, a method was needed to create simplified models of real-world systems to establish a better overview, achieve a unified understanding and to efficiently divide task among the projects team members. Among the benefits object-orientation have, compared to alternative philosophies for software development, the most important are the ability to understand and communicate about complex systems, building systems that are flexible to change, breaking down the systems in smaller pieces and the possibility to reuse systems, sub-systems and individual objects (Goldberg & Rubin, 1995). Fields where object-orientation have been successfully used in software development include securities trading, medical electronics, enterprise-wide information management, air traffic control, semiconductor manufacturing, interactive video gaming, telecommunications network management and astronomical research (Booch, 1996).

> Object-orientation is a way of looking at the world as "classes" of "objects" in order to model the real world more effectively than traditional structured software engineering or other methods of computer programming. Objects are descriptions of sets of behaviors, often in the real world but just as often in an imaginary world. Classes describe sets of objects which have shared properties. (Kanabar et al., 1996, p. 2)

Simula I and Simula 67 are considered the first programming languages built on object-orientation. They were developed by Ole-Johan Dahl and Kristen Nygaard in the 1960's while working at the Norwegian Computing Center in Oslo. Simula I and Simula 67 were never widely used but have had major influence on many of the modern programming languages (Dahl, 2002).

In fact, several of the most commonly used programming languages today are built on object-orientation and some examples are (Aho, 2004; Lee, 2017):

- Java
- Python
- C#
- C++
- Visual Basic .NET

In software engineering it is common to work iteratively with relatively short development cycles, and this can be managed effectively through object-orientation since the methodology allows for customer involvement during the development phases (Dué & Henderson-Sellers, 1995). Unlike software development, it is not common to use iterative development cycles when executing hardware-oriented projects (e.g. civil, automotive, mining, and oil & gas etc.) due to the cost of prototyping. It can, however, be argued that the engineering processes in hardware-oriented projects have iterative trademarks, where the system designed is developed iteratively throughout the project execution. Regardless, many of the benefits that object-oriented brought to software development are equally relevant for engineering projects with physical deliverables and object-oriented methodology was therefore soon adopted. This study has not been able to uncover what were the first applications of object-orientation for traditional, non-IT, engineering purposes, but as stated in section 1.3 the first version of the COMOS software was released in 1996 and has a long history through 23 years of development and ten major versions.

Owner of the COMOS software, Siemens AG, describe the platform's methodology as following: "object-oriented refers to the holistic description of a component or object in a single entity in a single database" ("Conceptual excellence", 2016). The object structure consists of a hierarchy of classes, with class objects on top (base objects), sub-classes and objects. Class objects are assigned properties which are shared between the objects in the same class, such as behavior and attributes that describe its function. When an object is created it inherits the properties that apply to the class/base object [ref. Figure 2]. But an object does not only inherit the properties of a base object, it also inherits general scripts and data links. These links create an web of information channels which ensure data consistency across class object, objects and technical document such as data sheets and schematics [ref. Figure 3]. This means that if an object parameter is changed, the object is deleted or replaced, the change is automatically updated everywhere in the system. This is an important aspect of the value that object-orientations bring to efficient engineering and project execution.

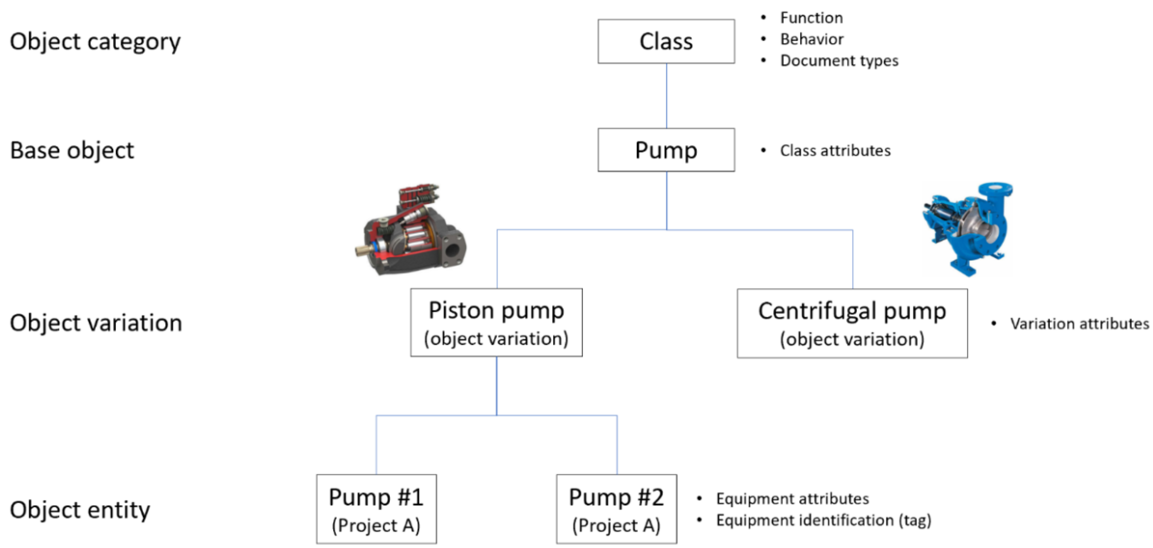

Figure 2 – Object structure example

In addition to the links the objects have to their base objects, they also establish links with other objects in the engineered system. Figure 3 visualize the connections of a pressure transmitter object modelled in COMOS, including the physical relations to its signal cable, its position in the process pipeline, representation on P&ID and SCD drawings, notes and functional properties in form of a function block. (Note that the figure only shows the links from the perspective of the pressure transmitter and each of the connected elements also have a web of connections of their own.) Working in the object-model environment, users can select any object and navigate directly to objects linked to it. This functionality ensures an intuitive and user-friendly way to navigate the system, improving system understanding and information access across disciplines.

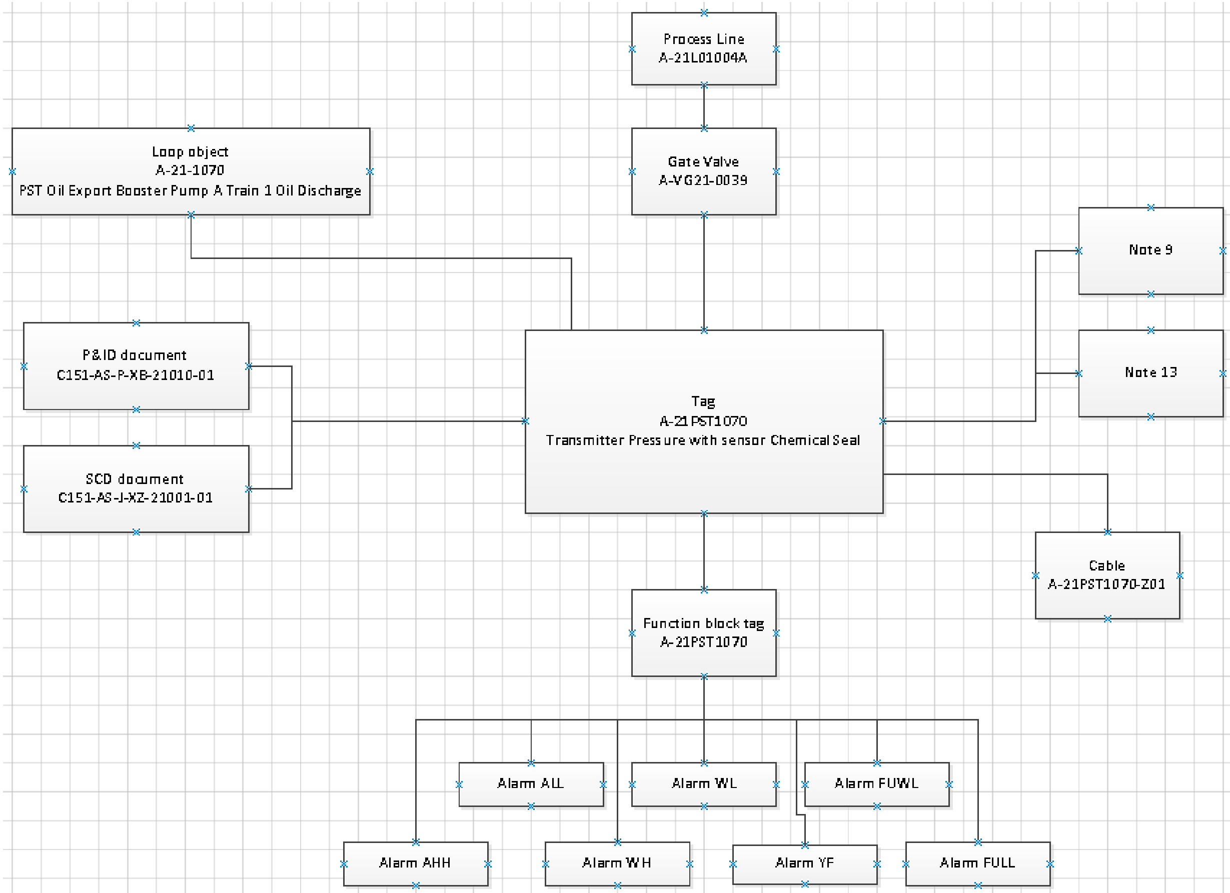

Figure 3 – Object relations example

3 Research method

It is important for researchers to be aware of philosophical commitments they make through their choice of research strategies, because it has significant impact on what they investigate and how (Johnson & Clark, 2006). Two ways of thinking about research philosophies are ontology and epistemology. Briefly explained, ontology describe how we define things and their relationships (nature of reality), while epistemology describe what leads one to believe that things are the way they are (what constitutes acceptable knowledge in a field of study). The two ways have important differences for how to view research processes, but the choice of ontology dictates the epistemology, which again dictates the research methodology and methods. The relationships between research philosophies, methods and data are visualized in the "research onion" [ref. Figure 4]. The third way of thinking about research philosophies is axiology. It describes how the researcher's values impact their research choices in social studies (Saunders et al., 2009). Heron (1996) argue that values guide all human actions, including choice of research topics and how the studies are conducted. For example, selecting one topic over another suggests that the researcher believe it is more important.

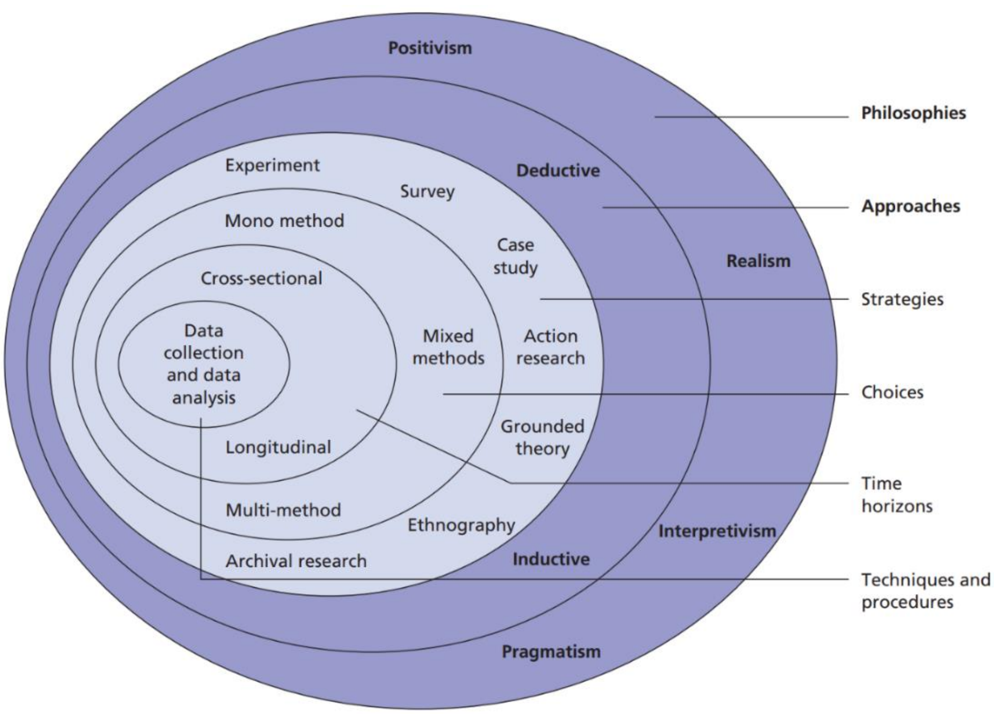

Figure 4 – research "onion" (Saunders et al., 2009, p. 108)

Ontology:

- Realism: Believes that one truth exists, and that truth does not change. Truth can be discovered by using objective measurements and it can be generalized.
- Relativism: Believes that there are multiple realities and that truth is shaped by context. Truth evolves and changes depending on experience and is relatable only in similar contexts.

Epistemology:

- Objective approach: The researcher does not influence the gathered data (outsiders view). Measures are taken to avoid external factors from impacting the research results. Realism ontology is related to objective epistemology.
- Emic approach: The researcher is involved in the study (insiders view), but his/her impact on the research is acknowledged and interaction is considered necessary to discover meaning. Relativism ontology is related to emic epistemology.

To exemplify; Scientific research (deductive) is designed to discover the truth through external investigation/experiments and is based on realism ontology and objective epistemology. On the other hand, phenomenological research (inductive) is designed to reveal personal experiences and discover truth through human interaction and is based on relativism ontology and emic epistemology. Saunders et al (2009) argue that the choice of research philosophy and methods is influenced by practical considerations, but the main influence is the researcher's world view regarding the relationship between knowledge and the process for how it is developed:

> The researcher who is concerned with facts, such as the resources needed in a manufacturing process, is likely to have a very different view on the way research should be conducted from the researcher concerned with the feelings and attitudes of the workers towards their managers in that same manufacturing process. Not only will their strategies and methods probably differ considerably, but so will their views on what is important and, perhaps more significantly, what is useful. (Saunders et al., 2009, p. 108)

Furthermore, to challenge own predisposition is only possible if one is aware of them and it is therefore important for researchers to understand their philosophical positions. The four ways to view the world are:

- **Positivism:** The researcher believes in observable social reality where the end-product can be law-like generalizations, like those produced by physical and natural science. The researcher is concerned with facts rather than impressions and believes that only observable phenomena can produce credible data. He/she usually rely on proven theory to develop own hypotheses, and positivism assumes that the researcher does not introduce feelings or biased opinions to the research. This is plausible because of the nature of the research, focusing on identifying observable truths not requiring the researcher's interpretation (Remenyi et al., 1998). The research is likely to use highly structured methods, emphasising on quantifiable results and statistical analysis (Gill & Johnson, 2002).

- **Realism:** Assumes that reality is independent from the mind and has a scientific approach to the development of knowledge, similar to positivism. There are two types of realism. The first type is called "direct realism" and it argues that what we observe through our senses is an accurate representation of the world. The second type is called "critical realism" and it argues that what we experience are only sensations of reality and that our senses can deceive us. One example is illusions that make things appear different than what they are. Direct realists would, however, argue that the illusions are a result of not having sufficient information. Because what we observe is only a part of the bigger picture, critical realists believe that researchers will only understand what is going on in the social world, if they understand the social structures that have given rise to the phenomena they are trying to study (Bhaskar, 1989). An important difference between the two directions is that direct realists believe that the world is relatively static, not distinguishing the individual from the group or the organization. While critical realists believe that each of these levels can change the researcher's perception of truth and that all aspects need to be studied. Critical realism is arguably more in line with the purpose of business and management research than direct realism (Saunders et al., 2009).

- **Interpretism:** Contrary to positivism, interpretism believes that the social world is too complex to be described by generalizing laws. Interpretism argue that if doing so, the researcher will not be able to reveal important details of the study. Interpretism also advocates that the researcher need to understand humans in their roles as social actors. The term “social actor” is important in interpretism and the belief is that all humans play roles in private and personal life. Role behavior is dictated by the interpretation of the role, and that one also interprets other people’s roles based on our own set of meanings. Interpretism therefore argues that the researcher must have an empathetic approach to research in order to understand the study subject’s perspective. Some argue that interpretism is especially relevant in business and management research, especially in fields of organizational behavior, marketing and resource management, because the situations studied in these fields are results of circumstances and individuals coming together at a specific time (Saunders et al., 2009).

- **Pragmatism:** Argue that the choice of philosophy should be dictated by the research question, because each philosophy has different qualities. Unless the research question clearly dictates that positivism or realism philosophy is used, pragmatism argues that it is possible to adopt variations of the philosophies. According to pragmatism, mixing qualitative and quantitative methods in a study is therefore possible and can even be highly appropriate (Saunders et al., 2009).

Since the intention of this research is to explore the effects of implementing object-oriented methodology for subsea projects, rather than providing conclusive answers, an exploratory approach is selected. The goal is to identify obstacles for achieving operational excellence and how these challenges can be solved by using object-oriented methodology. For exploratory research there are three principle methods (Saunders et al., 2009), and this paper has adopted the first two methods:

- Review of literature
- Interviewing subject experts
- Focus group interviews

It was also considered to perform a survey to map users experience with the COMOS platform in the context of project execution. The intention was to uncover if COMOS is perceived by its users to aid in efficient communication and flow of information. There are, however, a limited number of people in the organization who have experience using COMOS for subsea study/project execution. For this reason, it was concluded that the research population would be too small to yield representative data. One option was to interview Greenfield resources, who have long experience with COMOS, but the IT architecture and working methods are very different for the two business areas. It was therefore considered not relatable to evaluate the potential for Subsea based on user experience in Greenfield. It was instead concluded that in-depth interviews with key decisionmakers in the subsea organization would be the best option for acquiring relevant and accurate data. Exploratory research has a great advantage in being flexible and adaptable to change, allowing the researcher to adjust and narrow the focus as the study progresses. On the other hand, exploratory research suffers from that it is difficult to draw a definitive conclusion (Saunders et al., 2009).

This thesis aims to uncover patterns in data gathered from key personnel's personal experiences, mapped through in-depth interviews. Hence, the research is arguably based on relative ontology and emic philosophies. Furthermore, for studying if object-orientation can contribute towards achieving operational excellence for subsea oil and gas projects, it was considered using both quantitative and qualitative methods. The decision to use in-depth interviews instead of a survey was primarily a result of circumstances. Based on this and personal perception of the world, argument can be made that the author of this thesis has a pragmatic approach to research.

3.1 General Data Protection Regulation

The General Data Protection Regulations (GDPR) was approved by EU Parliament 27th April 2016 and took effect from 25th May 2018. The regulation harmonizes data privacy laws across Europe and shall ensure all EU citizens equal right to data privacy. In line with the GDPR, all aspects of privacy data are regulated, including data for research purposes (Regulation (EU) 2016/679 of the European Parliament and of the Council, 2016).

Collecting and processing personal information is fundamental to ensure quality and reliability in scientific research, and it was identified that GDPR can come in conflict with important research work, especially for data gathered in medical studies. For this reason, GDPR Article 9 and 89 defines certain special categories of personal data whose processing is forbidden in principle but permitted for research, or other purposes, in the public interest. Exceptions covered in Article 9 and 89 primarily focus on data concerning health, genetics and biometrics (Chassang, 2017).

The purpose of the research for this thesis does not fall into the above-mentioned categories and GDPR regulations are understood to apply. This paper therefore aims to discuss its findings without identifying the informants' individual opinion or belief, as communicated during the interviews. It is, however, considered important for the relevance and validity of the paper to identify the roles and responsibilities of the candidates. Since that is difficult without indirectly identifying the person, written consent to be identified by name and role has been received from each of the candidates. To disconnect the candidates from their replies, research results included in APPENDIX B – Research results are anonymized. The order of the interviews is random and does not correspond with the order of candidate's listed in section 3.2.

3.2 Interview candidates

The candidates interviewed in this study all have long experience working with subsea projects, have knowledge of the COMOS platform and varying level of influence over strategic decisions to implement the software platform for Subsea. The interviews were conducted in January, February and March of 2019.

- **Knut Nyborg:** Executive Vice President for Front End. Has 25 years of experience in Aker Solutions, including working with topside new builds and modifications, tender manager for Åsgard Subsea Compression project and vice president for Power & Process.
- **Øystein Haukvik:** Senior Vice President for subsea projects. Has long experience in Aker Solutions (Topside, MMO and Subsea), including as project owner for subsea projects and project director for Åsgard Subsea Compression project.
- **Morten Bentzon:** Vice President for Subsea PEM. Has long experience with subsea projects, including eight years in Aker Solutions, amongst other working as engineering manager and department manager for system engineering.
- **Espen Brathaug**: Senior Manager. Has 14 years of experience in Aker Solutions, including as engineering manager and as department manager for system engineering.
- **Petra Margareta Jacoby**: Engineering Manager. Has 12 years of experience in Aker Solutions, including as system lead / engineering manager for SPS projects, and system lead for Jansz subsea compression FEED.
- **Tylar Bunger:** Engineering Manager. Has long experience working with subsea projects, including nine years in Aker Solutions, working as interface and system lead for Åsgard Subsea Compression project and engineering manager for Jansz subsea compression study and FEED.

3.3 Sources for error

In a research situation it is important that the researcher is aware of the current state of knowledge for the research topic (Gill & Johnson, 2002). It is also essential to critically evaluate the quality and validity of available literature, especially if referenced in own research. Because referencing works that are not up to par can negatively impact an otherwise well performed study. To critically review literature the researcher need to have back-ground knowledge, understanding and ability to analyze and reflect upon the literature to make reasoned judgement (Saunders et al., 2009). Research for this thesis found many publications about object-orientation for IT and software development, but it has proven challenging to find relevant articles on object-orientation in hardware-oriented businesses. Furthermore, several of the articles found are more than 20 years old, which raise the question of relevance given how quickly the digital technology is changing. Due to the challenges with locating relevant papers about the COMOS software platform, it was necessary to rely on brochures and presentations issued by the product owner. Siemens AG obviously has commercial interests in promoting their product portfolio and statements in the brochures have therefore been challenged through discussions and clarifications with internal product owners and super-users for the COMOS platform. These people have not been interviewed, however, since the purpose of the study is to evaluate how object-orientation can contribute to operational excellence, not to evaluate COMOS as a tool.

Furthermore, research design consists of several steps, from formulating a hypothesis, deciding on the data collection method, selecting a research population and finally to analyze the collected data. It is important that the researcher is mindful that each step has sources of error that can impact the quality of the study, but through awareness the errors can be neutralized or minimized. Undertaking a study in a company where the researcher works has positive sides, because he/she can spend less time on familiarizing to understand the inner workings of the organization, but the role of practitioner-researcher also has some disadvantages. In this role one must be especially cautious of assumptions and preconceptions which can prevent from exploring valuable aspects that can enrich the study. Furthermore, the role of practitioner-researcher can dissuade the researcher from asking “basic” questions due to the notion that he/she should already know the answer, which can prevent from uncovering important aspects (Saunders et al., 2009).

To achieve nuanced and accurate feedback in qualitative research, it is recommended to interview multiple candidates. A general guideline is that sufficient input has been reached when theoretical saturation is achieved, meaning when no new concepts emerge from the data. To be useful the collected data must be analyzed to develop a theory. But systematic errors can be introduced in the findings, both during information gathering and when analyzing the data. Examples of systematic errors are to ask leading questions or letting biased opinions affect how the input is interpreted. To mitigate, it is recommended that interviews are recorded and transcribed, noting down both *what* is said and *how* the candidate said it. Furthermore, to reduce the likelihood of the researcher's biased interpretations affecting the results, he/she can review interview recordings with a third party and discuss how to interpret them (Saunders et al., 2009).

It can be argued that some of the interview questions asked for this study are steering the conversation to specific discussion topics [ref. APPENDIX B – Research results]. Researchers should always refrain from making assumptions for what the interview candidates means to say or "put words in their mouths". But a good qualitative research has both breadth and depth, and it is therefore necessary to use a combination of content mapping and content mining questions (Ritchie et al., 2013). Structuring the interviews to be fully open is usually not practical, because it would require a significant number of interviews to uncover all the details. It can therefore be necessary to steer the conversation towards specific topics, to balance the need for practical research execution against acquiring accurate input. All the while being conscious of the pitfalls of introducing own beliefs or opinions.

4 Research results

The questions for the interviews conducted as part of this study were prepared and selected based on preliminary research of literature and discussions with stakeholders. Several revisions of questions were developed to ensure that the interviews would cover the identified topics, without introducing the researchers biased opinions. Once deemed suitable a test interview was conducted with a candidate that was familiar with COMOS and the implementation initiative. The test candidate was not presented with the questions prior to the interview. The conclusion from the test interview was that all identified topics were covered and that the time required for completing the interviews was acceptable, but it was agreed that it would be beneficial if the candidates were presented with the questions upfront.

The six interviews were completed from January to March 2019 and each interview was recorded. Shortly after, a summary was written, listing all the information that had been provided and systemized in a matrix. This was done to simplify comparison of the gathered data. In an effort to ensure unbiased interpretation, the recordings were reviewed several times for each note that was made. In line with GDPR regulation for storing data the interview recordings were deleted after being analyzed [ref. section 3.1].

Together with research of third-party literature, the analysis of the information gathered in the six interviews form the basis for the discussion and conclusion chapters in this thesis. Due to the amount of information provided in the interviews it was not possible to cover all aspects in detail. Readers who wish to study the results can find the summary notes in APPENDIX B – Research results.

5 Discussion

As stated earlier, this paper defines operational excellence as doing all the right things and doing them optimally efficiently. Object-orientation is obviously not the solution for all challenges Subsea is faced with, but through research of third-party publications and analysis of information gathered from interviews with key informants in the Aker Solutions organization, this study has identified four topics which are believed to have great potential for improving execution and control. The four identified topics are digitalization, collaborative engineering, project control, and knowledge management and reuse. Each topic is discussed in detail in separate sections below and their main benefits and challenges are summarized in Table 4.

	Benefits:	**Challenges:**
Digitalization:	• Centralized database for engineering information • Data format and information accessibility • Hub for connecting third party applications • Ease of data access through web browser interface	• Change resistance: This is a major change initiative in terms of working process and culture • Complexity of software engineering required to establish automatic data exchange across platforms
Collaborative engineering	• Cross location working platform • Real-time update of information • Visual multi-discipline system model • Mitigates data duplication • Reduces number of interfaces • More efficient information flow • Integrated engineering tool for controls systems design	• Change of working method (process and culture) • Accuracy, maturity and transparency of the data
Project control	• Better progress plans by measuring on data parameters instead of document status • More specific and relevant project execution model (PEM)	• Roles and responsibilities for updating data • Revision control • Document / data review process (internally and with client)
Knowledge management and reuse	• Library of standardized objects • Archive for ongoing and finished projects • Controlled copy functionality • More efficient onboarding	• Risk of reusing unverified design • Risk of reusing verified design for wrong applications • Motivating users to document knowledge

Table 4 – Benefits and challenges with object-orientation

5.1 Digitalization

Digitalization is arguably one of the most important buzzwords in the oil and gas industry when this paper is written. Contractors are under pressure to offer cheaper projects and services, with feedback from management being that cost is *the* most important factor for winning work in today's market. Achieving more efficient project execution by reducing "waste" is considered the key to lower cost, where the term "waste" comes from LEAN methodology and is defined as any activity (time or resources) that does not add value towards the end goal (Womack & Jones, 1996). It is not realistic to eliminate all waste because of the human factor, but there is undeniably a huge potential for improvement. In today's project execution environment, Subsea employees are faced with numerous tools which serve specific needs, including but not limited to creating schedules, 3D models, drawings, data sheets, procedures, reports, cost estimates, risk registers and progress reports. The problem is that many of the software tools do not interact with each other which mean that users must extract, exchange and update information manually. The result is duplicated and overlapping information circulating in the project sphere. Experience shows that duplicated information is difficult to manage and that one ends up with project members maintaining and updating almost identical files, serving each one's needs. Furthermore, since project information is spread over many documents and software interconnection is missing, the documentation must be manually revised when engineering changes are introduced. Keeping track of all places where information has been used is a tedious task and there are numerous examples of incorrect, non-updated information leading to costly errors. In other words, lack of data consistency is not only preventing efficient execution, it also poses a risk to quality.

To facilitate automated information management and exchange is clearly an important driver for digitalization. Ideally a company's entire software portfolio should be interconnected, using a data warehouse to store, update and exchange information. But facilitating an unobstructed flow of information requires that the information is stored in a format that can be read and edited across platforms. In Aker Solutions, Greenfield has used COMOS since 2006 and has achieved a high level of data integrations by using software which seamlessly integrated with the COMOS platform [ref. Figure 5].

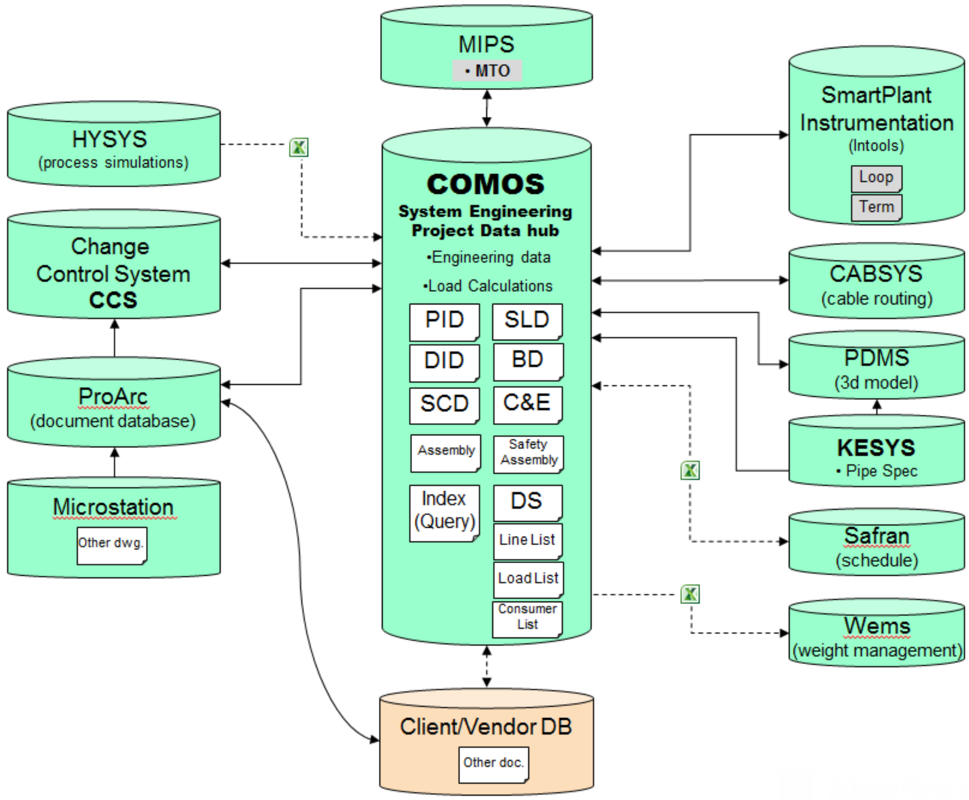

Figure 5 – Aker Solutions Greenfield IT system architecture

However, while Greenfield primarily is an engineering and procurement-oriented organization, Subsea has additional challenges related to enterprise resource management (ERP) such as: manufacturing, stock management, logistics etc. That is one of the reasons why Subsea has built their IT system architecture around the SAP Business Suite [ref. Figure 6]. The SAP platform uses a material philosophy, where products are assigned unique material numbers and specifications and documentation are linked to the material. Material numbers can be used across projects, and item identification is achieved by assigning specific serial numbers. If used correctly, material number orientation gives flexibility and promotes standardization by allowing projects to reuse existing materials, but the reality is that new material numbers are too often created instead of reusing existing ones. An internal improvement initiative to standardize the SAP product portfolio in Aker Solutions found that as many as 30.000 new material numbers were created every year, which is five times as many as required (Benbow, 2019). The research for this paper indicates that client specific requirements, poor library search functionalities and unrestricted access to create new materials are important reasons for the rapid increase of material numbers. The research also reveals that there are limitations with the SAP platform which prevents seamless software integration. The limitations are primarily related to SAP's interface capabilities and cost of developing and implementing new functionality.

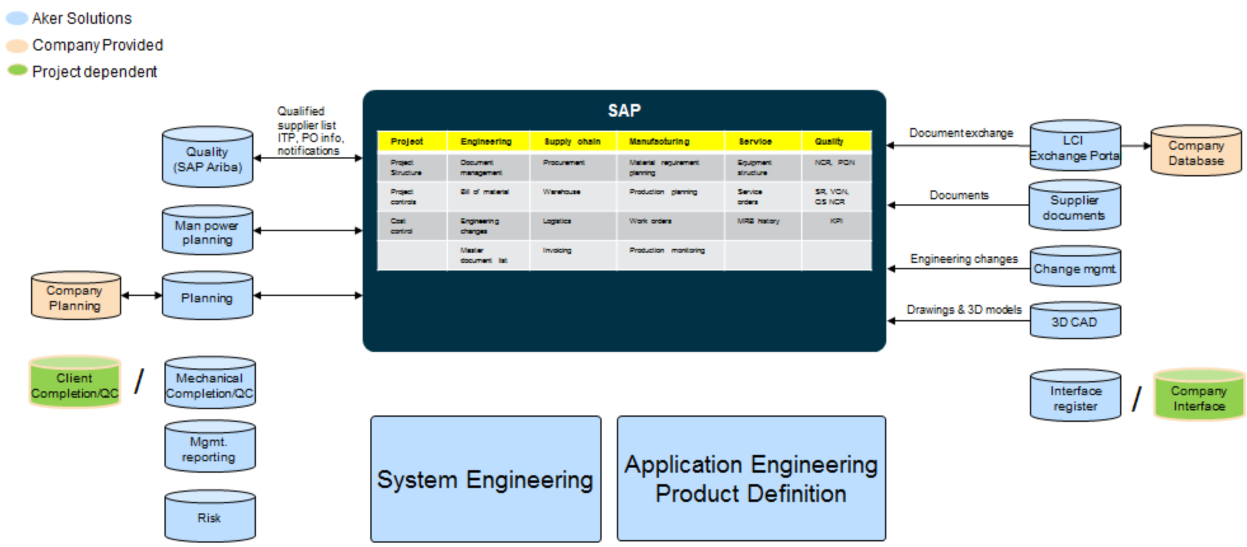

Figure 6 – Aker Solutions Subsea IT system architecture (present)

Despite the challenges with the SAP Business Suite, the interviewed candidates appear to not believe it is realistic to replace SAP in Subsea, and perhaps not even preferable. For a company the size of Aker Solutions, changes in IT architecture can have significant cost impact related to down time and reduced efficiency, which in worst case can impact contractual obligations. In short term it is therefore considered necessary to tailor the IT system in a way that maintains SAP's functionality, while integrating the benefits of object-orientation. As described in chapter 1, COMOS is the obvious choice of software platform for Subsea because of the synergy of sharing platform and related support organization with Greenfield. Furthermore, COMOS has proven to be a flexible platform for connecting third party applications. As part of the business case study to evaluate implementation of COMOS in Subsea, an IT architecture vision was created [ref. Figure 7]. As shown in the figure, the envisioned system architecture integrates system engineering and product definition into COMOS and establishes data links with project control tools, while retaining SAP functionality. (Note that the envisioned IT system architecture is an early revision, and changes are expected as the implementation project progresses, and technical integration feasibility becomes clearer.)

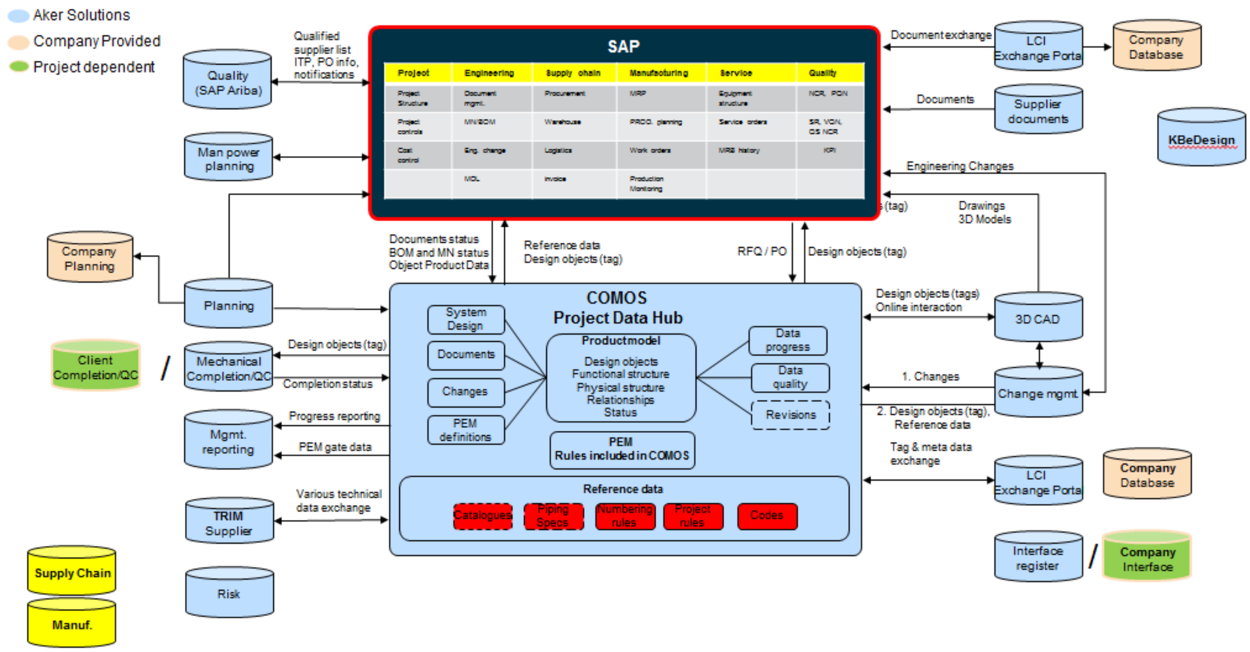

Figure 7 - Aker Solutions Subsea IT system architecture (vision)

Being a P&ID-oriented software it can be argued that COMOS is more valuable for ASP projects, compared to traditional SPS projects. While the functional parameters described in the process & instrument diagram are vital for system definition in ASP projects, product oriented SPS projects have less use for P&ID's in their system definition activities. However, similar for the two project types is that both require complex control systems, for which the engineering design processes are very much alike. The research for this paper revealed what appears to be a unison belief among the interviewed candidates, that improving engineering execution for the controls discipline is one of the most important success factors for using COMOS in Subsea. The feedback was that controls engineering for subsea is outdated, working with functional descriptions which is something topside stopped doing "20 years ago", now using function blocks instead. Function block diagrams (FBD) is considered the industry norm for designing automation systems and arguments were made that subsea needs to follow in topside's footsteps:

> Topside projects use system controls diagram, controls loop diagrams etc. which specify how each controls loop shall be. Typically, an instrument is an object with attributes, but in Subsea it is just a part number. Through COMOS any sensor is assigned applicable alarm signals and control loops, building up the full automation system. By using this functionality, we can solve what has always been a problem in Subsea, namely the integration with the topside control system. (candidate F, 2019)

The purpose of the subsea control system is to monitor and safely operate the subsea production system, where the controls system is driven by three main parameters; input, logic functions and output. Input can come from sensors (i.e. pressure, temperature, flow, level etc.) or manual operator input. Input is continuously monitored and interpreted by the controls system software, which generates output based on predefined sensor parameters and cause & effect logic. Examples of output can be a signal to open or shut valves, inject chemicals, or to ramp up or down pumps and compressors. Designing the electrical and instrumentation system is normally done by the SPS/ASP contractor, while delivering the safety automation system (SAS), including software, is done by a third-party supplier. The research for this paper found that the controls system design in Subsea is a highly manual process, which could benefit greatly from being automated. To visualize the electrical and instrument system design in an organized way, a single-line top assembly schematic is created. Where every cable in the control system, be it electrical or optical, is represented by a separate line. However, when reaching detail design, it is necessary to have schematics where the wiring is shown on a pin level. As of today, the transition from single line to multi-line schematics is a manual task and the same goes for creating input/output lists and cause & effect logic. This is a functionality that COMOS has and can manage through object attributes, ensuring efficiency, information consistency and quality of design. In addition to the wiring, automation is a vital part of the controls system. Automation hardware include programmable logic controllers (PLCs) which are a type of computer and FBD is a graphical language for programming PLC design. Each function block in the FBD is assigned input and output parameters and the blocks are linked together with lines to visualize the relations between them (Pavlovic & Ehrich, 2010). Through its Automation module, COMOS offers functionality for creating function block diagrams based on instrument object attributes on the P&ID, automating parts of the controls systems design process [ref. COMOS Automation]. By executing both process and controls engineering in COMOS, it is therefore possible to capitalize on the synergies of the object model, where design elements are standardized and where changes to the system design are updated automatically. This has the potential to both reduce engineering durations and improve quality (Chen et al., 1996). Like the possibility to create function block diagrams based on P&ID, COMOS also offer functionality to automatically generate wiring diagrams, terminal diagrams, cable lists, parts and order lists based on the single line diagram and its object attributes. To compliment the digitalization and automation opportunities that are offered through object-orientation, working in a single entity data model also has the benefit of facilitating engineering collaboration across disciplines by improving the flow of information. This will be further discussed in section 5.2.

Improving efficiency and quality through data consistency is clearly an important driver for digitalization, but the new business opportunities that are unlocked through data accessibility is also an important factor. Another buzzword in the oil and gas industry in 2019 is “digital twin”, and in February 2019 Aker Solutions announced that they had secured their first contract for delivering this service for a subsea asset:

> The digital twin will become an advanced replacement to traditional paper-based handbooks and equipment documentation, ensuring that all relevant engineering data is held centrally in a single, interactive and searchable solution. It will be built on a cloud-based architecture capable of processing live data and ensuring that vital engineering information is kept up to date at all times. (“Aker Solutions to Develop Digital Twin for Wintershall’s Nova Field”, 2019)

With SAP being the primary database for Subsea, it is possible to create a digital model that provide direct access to SAP directories containing equipment relevant documentation. But to offer a truly interactive model with custom dashboards displaying specific engineering information parameters, the data need to be stored in a different format, for example, as object attributes. Furthermore, in addition to serving as a digital production system information platform, the intention is also to include condition monitoring functionality in the digital twin, with the purpose to achieve production optimization and more predictable maintenance. Condition monitoring and maintenance management are both functionalities that are offered through the COMOS Operations module [ref. COMOS Operations]. By offering condition monitoring services, Aker Solutions is moving into what has predominantly been the domain of the oil companies, namely field operations. The interviews revealed that the candidates do not consider it realistic that the major operators will request these services, but that there are several small and medium-sized oil companies that do not have similar organizational capacity, or strategy, and who are open to outsource these activities. This is potentially a huge business opportunity.

Mentioned above are some of the benefits that have been identified in the context of digitalization through implementing an object-oriented data model. There are obviously other benefits which have not been identified or covered in this paper, but there are also several challenges which need to be overcome to capitalize on the opportunities. The interviewed candidates addressed two main types of challenges that need to be overcome; The first being the technical aspect and the second being management of change. Working with several software solutions, each with different owners and system architectures, it is not guaranteed that it is possible to achieve seamless data integration. Especially the integration with SAP is highlighted to be a potential showstopper for achieving the goal of having integrated software architecture. When this paper is being submitted, IT consultants are working to establish data links for information exchange between SAP and COMOS. While the initial results are promising, it is a long way to go and it is important that this work progresses, so that obstacles can be identified and tackled as soon as possible. Furthermore, there are many ongoing digitalization initiatives in Aker Solutions aimed at improving work processes. It is important that these initiatives are aligned towards the company’s vision and road map, both to avoid overlapping or conflicting initiatives and to ensure optimal process quality and efficiency.

The initiative to implement COMOS in Subsea is also a major change initiative, which will affect the way many Subsea employees are working. Because COMOS is not just a new tool, it is a database and a new working method. Most change initiatives face some sort of change resistance and several scholars claim that as many as 70% of all change initiatives fail (Beer & Nohria, 2000; Sirkin et al., 2005). Hughes (2011) argues that there is no empirical evidence to support these numbers and there are arguably nuances to the definitions of “success” and “failure”. The underlying message is still clear, change initiatives very often fail. Kotter (1995) claimed that the most successful change initiatives start when groups or individuals identify approaching risk elements, such as expiring patents, decline in margins or changes in market trends. In other words, when there is a sense of urgency. Kotter's view on employee involvement in change processes is also supported by Beer et al. (1993), who argue that the most effective way to reach enduring organizational change is if it starts at the periphery of the organization and move steadily towards the corporate core. Their study found that changes initiated by corporate headquarter and implemented through the formal organizational structure often failed. Successful changes, on the other hand, were usually initiated in plants and divisions by general managers who created ad hoc change teams in their quest for solving concrete business-related problems, without regards for formal organizational structures. One important success factor, in this context, is the employee's commitment that is developed through collectively analysing the problems, creating a shared vision and reaching consensus for what and how to change. Since the changes are based on the employee's own decisions, their change resistance is reduced. In the case of COMOS implementation for Subsea, the sense of urgency is arguably present after what has perhaps been the worst oil and gas market downturn in history. It also appears that the decision to use COMOS for project execution initially started on middle management level years ago, but now has broad support from both executive and discipline managers. Through formal interview and informal discussions for this research, it appears to be a widely shared opinion that the Subsea organization need to work more efficiently, and there is a positive attitude towards object-orientation and COMOS being the solution for doing so. That is arguably a good foundation for starting a major change initiative.

5.2 Collaborative engineering

In all projects over a certain size there is a need for project team members to interact and exchange information to collectively progress. The bigger the scope of the project, the more important efficient information flow becomes for successful execution. Communication between sites can be especially difficult, but to stay competitive many organizations execute projects from different locations around the globe. Some of the reasons why corporations choose cross location execution models are cost, market presence, logistics and access to personnel with specific qualifications (Fan et al., 2007; Townsend & Hendrickson, 1998). Aker Solutions for example, has 53 different locations in 20 countries, and the delivery center philosophy is an important part of the company's strategy for strong execution capacity and cost efficiency (Aker Solutions, 2019). There are, however, several challenges with cross location execution, especially related to work sharing and communication, but many of these challenges are ones that object-orientation is specifically designed to solve.

Building on object-oriented methodology, COMOS offers a data platform to construct simplified virtual models of real-world processing systems. In these model's users can assign properties to the individual components and create and delegate engineering workflows based on the process system P&ID's. The purpose is to improve productivity and quality by enabling a continuous flow of data which is accessible for all project participants. By having the engineering team working in the same model, where data is updated in real-time, users in different locations always have access to the latest information. Such a cooperative environment obviously has several benefits. First that the need for internal interface coordination is in principle eliminated, and secondly, collaboration and work sharing across time zones are made easier due to the unrestricted flow of information. The research for this paper found that the interviewed candidates perceived information exchange to be a major challenge, not only between different sites, but also between disciplines working from the same location.

For oil and gas projects the norm has been for operators to divide field development contracts between multiple contractors. This is done to capitalize on individual contractors' specialties and to reduce risk, but it also means that projects have external interfaces that need to be managed, and interface registers are used to formalize design parameters between the parties. To create, follow up and close interfaces is time consuming, so it is neither preferable nor intended to use the interfaces registers for internal information exchange. Still, it appears that interfaces are in fact being used regularly as tools for internal information exchange. The reason is believed to be that users are dependent on information to progress their own work, but that documents containing the information are not available. Project members therefore raise interfaces to obtain the required input, or at least to document that the input has been pursued. However, the challenge of information availability being linked to documents is only one of several factors which can affect information sharing in an organization. Other examples are that people guard their own work or that group mentality separate teams, disciplines or departments and prevent efficient communication. This is especially relevant in an object-oriented environment where the project information is stored in a database. Kimmerle & Cress (2008) argued that unwillingness to share knowledge is understandable from a psychological perspective, because sharing takes time and effort and weakens the individual's position in the organization (Kimmerle & Cress, 2008):

> An individual group member does not benefit from sharing his/her own knowledge with others. On the contrary, he/she saves time and remains in a leading or advantaged position by withholding information. On these grounds, withholding information is the most advantageous strategy. (Kimmerle & Cress, 2008, p. 86)

For object-orientation to be efficient, it is essential that project members continuously populate object attributes with updated information. This way the project information is made available for everyone, through the object model, which means that users do not need to wait for formal release of documents. If used as intended, this working method can potentially reduce the need for exchanging project information through other channels. Be it formal channels such as interface registers or informal channels such as emails and verbal communication. But it is assumed that it will be difficult to convince everyone to share information freely and to prioritize updating object attributes. Especially when working in a hectic project environment where the team members are under constant pressure to deliver on schedule and do not necessarily need the information themselves. To achieve such a state of working environment is arguably a question of organizational culture, which cannot simply be fixed by updated work instructions.

Historically, the most common working process for engineering has been the workflow model, where one employee works on a task at the time, before passing it to the next contributor. This method allows for a structured working process, without much need for communication and coordination, but it is not very time efficient. The philosophy of concurrent engineering design argue that by allowing multiple engineers/designers to work in parallel on the same task, one can both reduce schedule duration and improve the quality of design (Kung et al., 1999). One example is design for manufacturing, where concurrent engineering dictates that product and process decisions shall be made in parallel as much as possible. By incorporating production decisions in the early stages of product design, the need for re-design and re-work is reduced (Pullan et al., 2012). Wick and Bakerjian (1993) found that product design only amount to 8% of a mechanical product's budget, but that its design determines as much as 80% of the products life-cycle cost. Once the design is frozen it is difficult to change life-cycle cost, underlining the importance of early engagement from fabricators and end users in the product design phase. For a company such as Aker Solutions, whose business strategy is to deliver intricate equipment by way of engineering design and fabrication, this is obviously a highly relevant issue. But engineering design processes requires a substantial amount of complex data which traditional database systems are not well equipped to handle. To achieve a successful concurrent design process therefore requires extensive communication and coordination, and object-orientation is argued to be the superior as data model in such an engineering design environment (Du & Wolfe, 1997). As described in section 1.3 the possibility for multiple users to work simultaneously on a task is a key functionality with COMOS, making the platform suitable for facilitating collaborative engineering processes.

However, even if one manages to develop a culture for open information sharing and collaboration there are additional challenges that also must be considered, such as information maturity. Throughout a project the information becomes increasingly more accurate as the project progresses. But to ensure that users does not make decisions based on wrong data quality, it is important to be able to judge maturity of the input at the point of use. In this context document-orientation has an advantage since the information maturity is directly related to the document's release status. That is more difficult when using an equipment attribute approach. Attributes in COMOS can at any time be edited by all users, but because of the vast number of parameters in an object model, it would be an unbearable task to status-set and maintain information maturity for each attribute. With the exceptions of a few unique parameters such as weight, Greenfield has therefore chosen to not configure COMOS to allow for status setting individual attributes. While it is possible to status set maturity on an object level, Greenfield has decided to describe object information maturity through PEM. This is done by linking PEM gate reviews with attributes and defining at what time specific attributes must be populated. Subsea on the other hand has structured their PEM model based on documentation status, but the interviewed candidate's assessment is that the subsea approach has flaws. Several of the candidates instead expressed that an attribute-oriented PEM approach, like Greenfield use, probably would improve project control in Subsea.

5.3 Project control

Accurately understanding project status is very important for successful project management. If left undiscovered, wrong decisions or unidentified tasks can potentially lead to critical schedule and cost overruns. This is especially relevant for large construction projects where investments can be in the billion-dollar order and the projects last for years. It is therefore important to have robust work processes and accurate reporting methods to maintain good project control. To ensure standardized and systematic approach to project execution, many project-oriented organizations have internal project execution models. These models outline the project steps and tasks that must be completed for each step. The model used in Aker Solutions is developed in-house and is called PEM. Through predefined PEM gate reviews, the project teams evaluate milestone status and decide if the project is mature enough to proceed to the next phase. However, while the project execution model is used to steer the project from a high-level perspective, it is the schedule that is used for measuring the project's progress, both on a detail level and aggregated.

In the context of subsea project execution, the scope is normally grouped in three main disciplines: engineering, procurement and construction (EPC). The activities in these three discipline areas are inherently different, but one shared factor is the time it takes to complete the tasks. Schedules are therefore created by listing project activities and assigning each activity with an hour budget. Throughout the project the progress is measured by registering actual hours spent and comparing with the planned activity durations. Linking activities with hour bookings is done using a work breakdown structure (WBS). By plotting the planned and actual hours an S-curve is created, which indicate if the project is on, ahead of, or behind schedule. Based on the S-curve trend one can also estimate how the progress is expected to develop going forward. This is a well-established method for project planning, but there are also some challenges with measuring project progress based on activity breakdown. One challenge is that it is difficult to identify all activities and accurately predict how long time they will take to complete. Another challenge is to measure on the right detail level. Having enough details to accurately monitor the progress, but without being so detailed that it becomes impossible to manage.

Subsea projects consist of numerous engineering activities, so to group the activities in a logical and manageable way, the general approach has been to monitor engineering progress based on release status for documents included in the master document list (MDL). The MDL is defined early in the project and each document on the list is assigned an manhour budget to complete. However, the interviews revealed that the candidates believe that measuring based on MDL is an inaccurate method for measuring engineering progress. As one candidate stated, “It was previously believed that MDL documents accounted for 80% of the engineering scope, but we have now realized that it only accounts for maximum 50%” (candidate A, 2019). Creating drawings is one example that illustrates the gap that can exist between planned and actual engineering hours. In Subsea, a drawing, for which engineering progress is measured, will usually require far less time to complete than it takes to develop the 3D model, which is the prerequisite for creating the drawing but for which progress is not measured. The gap between planned and actual level of effort for engineering obviously impacts the reliability of progress monitoring, but it is not the only challenge with MDL-oriented project control. Two other challenges were pointed out by candidate B who stated “To measure engineering based on MDL can easily give misleading information. “Started” status for documents can for example be used to gain measured progress without any real progress to engineering” and “to measure based on MDL is like chasing ghosts, because status is outdated by the time the status is reported and analyzed” (candidate B, 2019). The purpose of monitoring progress is arguably to offer a proactive steering mechanism, but when status reports are consistently outdated the control process at best allow for early action damage control.

Greenfield, on the other hand, has a different approach to controlling engineering progress than Subsea. Instead of measuring progress based on MDL status, they primarily measure based on population of object model data attributes and 3D model maturity. It can be argued that by working object-oriented, documentation such as data sheets and schematics are reports of data from the object and 3D models, instead of being the actual information carriers. But for this progress control method to work, one is dependent on having integrated IT architecture, connecting the 3D model with the object model. For Greenfield projects the 3D model mostly consists of main steel and piping, which are structural elements that the E3D software is well suited for modelling. E3D is also integrated with COMOS and offer data exchange on an object level. E3D is, however, not well suited for creating detailed assemblies or fine tolerance machining drawings, but since the Greenfield equipment is procured on a skid level, highly detailed 3D models are not usually required. As these functionalities are important for Subsea, they have chosen SolidWorks as their primary 3D modelling tool. As of today, SolidWorks is not integrated with COMOS to facilitate data exchange on an object level. It is unclear if this functionality can be developed, but the research for this thesis reveals skepticism that the SolidWorks architecture allows for similar integration as E3D does.

Furthermore, section 5.2 touches upon the challenge of status setting information maturity, in the context of working collaboratively and object-oriented. This challenge is equally relevant for project control, since one must be able to trust that the measured parameters have real progress. Greenfield solves this by linking data maturity and associated data quality requirements to the project execution model, where gate review requirements dictate which parameters that must be populated at the different stages. It is then the discipline leads' responsibility to ensure that the information requirements specified in PEM are adhered to. Subsea PEM, however, primarily use MDL document status for evaluating project status. As candidate D stated "We need to think about PEM in a different way in Subsea. It's unclear what PEM actually controls, besides the check points that specific activities have been done." (candidate D, 2019). One proposal is for Subsea to follow in Greenfield's footsteps by moving away from measuring engineering based on documents, instead focusing on data population. Because it is arguably the information that is indirectly measured through the documents that are important, not the information vessels (document). This was highlighted by candidate F who stated "Perhaps it is then more relevant and important to have input control, rather than output control. With COMOS the drawings, tables and datasheets are output reports which are automatically generated from the model." (candidate F, 2019). By focusing on object attribute status instead of documents it is also possible to increase the information granularity. As discussed above, too much information can be problematic since it makes the reporting impossible to manage. But by measuring object model data population automatically through PEM, using the data consistency and automation that object-orientation and COMOS offers, Subsea can potentially increase information granularity, improve status reporting quality and reduce the amount of work required for reporting. It is, however, not considered realistic to adapt object-orientation methodology and updating Subsea PEM in a one-step process, and yet again the IT architecture creates challenges. While Greenfield use the planning software tool Safran, which has established integration with COMOS, Subsea rely on Primavera which is not integrated with COMOS as of today. It is therefore expected that a hybrid solution will be necessary, combining MDL-oriented and attribute-oriented progress measurement methods, at least during a transition period. Furthermore, the document-oriented approach also has a strength in terms of information review and validation. To control that engineering is done in accordance with applicable standards and best practice methods, critical MDL documents are issued to the client for multi-discipline reviews. Complimenting internal review processes, these reviews contribute to ensuring quality of engineering design. If decided to move away from the MDL-oriented information exchange/monitoring process, an alternative method for information review must be developed. Furthermore, drawings and documents will obviously not disappear entirely, but if new processes and tools are implemented without removing some of the old, one merely ends up with duplicated work. As stated by candidate F:

> “We need to evaluate how object-orientation/COMOS affect LCI. If we still need to deliver "flat" drawings, we are destroying the digital value that we've built up. To succeed it's not enough to work technical, with IT and system engineering, we also need to consider how this effects LCI, contract and intellectual property (IP).” (candidate F, 2019)

5.4 Knowledge management and reuse

To execute projects with extensive scope of work and high level of technical complexity requires large project teams with discipline experts in many fields. As a result, companies who have a business model for project execution tend to have large project-oriented organizations. In these so-called knowledge-based organizations the workforce primarily consist of discipline experts, and decision making at all levels is important for these organizations to operate efficiently (Drucker, 2004). One example of a knowledge-based organization is IBM, who's former CEO, Samuel J. Palmisano argued that in a company as large as IBM, it would smother the organization to have a strict hierarchical management and that decentralized decisions is the only way they can operate (Hemp & A. Stewart, 2004). While flat organizational structures allow for more efficient lines of communication, a drawback is that employee empowerment and information decentralization can lead to fragmented knowledge and loss of organizational learning. "Projects contexts, underlying idea progressions, and rationales behind key decisions are effectively lost as an organizational resource when project team members leave for new assignments and human memory fade" (Weiser & Morrison, 1998, p. 150). However, strategically established IT systems can enhance accessibility to knowledge repositories, promote flat organizational structure and ensure information retention during employee turnover (Gong & Greenwood, 2012).

Knowledge management is generally divided in two categories, the personalization approaches that focus on human resources and communication, and codification approaches that focus on the collection and organization of knowledge (McMahon et al., 2004). In the context of knowledge management through object-orientation, this thesis focuses on the latter. Brandt et al (2008) argue that knowledge about engineering design processes is one of the most valuable assets of a modern enterprise, but to be fully exploited the competence must be documented and shared. That can only be done by converting implicit individual know-how to explicit repository information. However, due to the information complexity it is neither practical nor realistic to gather all knowledge items in a single information entity. Instead, Brandt et al (2008) propose that a better method for knowledge management is to reference metadata (document type, revision, storage location etc.) to documentation containing detailed information, in addition to capturing the context of when and why the information was captured. Together, this information allows for retrieving experience knowledge for a particular situation and to evaluate its applicability. One approach to this kind of codified knowledge management is through object-orientation.

> By connecting ProductObjects to ProcessObjects, it becomes possible to provide information about the organizational context (i.e., the work processes and decision-making procedures) in which a product was created, used, or modified. This allows to answer questions such as “What has this model file been utilized for?” or “Which decisions have been taken on the basis of this data?”. That is, by analyzing the organizational context associated with some design knowledge, one can evaluate the applicability of the retrieved knowledge to the current work situation. (Brandt et al., 2008, p. 333)

Experienced organizations usually have well established routines and data management systems for generating, processing and storing formal documentation such as manuals, procedures, reports and drawings. But throughout a project’s life span the team members will also generate a vast amount of informal data such as email correspondence, notes, text documents, spreadsheets and presentations. Some of this information will be preserved by being uploading to shared project storage areas, but in many cases the data is stored on each project member’s local hard drive. It is therefore a significant risk that the data is lost when team members leave the project or the company altogether. Much of the informal data will be duplicates or irrelevant, but it can also contain valuable information that is not captured in the formal documentation. For example, information about decision processes that can prove valuable long after the project is delivered, and perhaps even more so for reuse in new projects. For project information to be documented accurately it is important that project members index, link and archive information continuously as the project progresses. To only capture lessons learnt as part of project close-out is problematic because human memories fade, so unless it is documented immediately the information accuracy will suffer. However, during project execution the team members are usually more concerned with completing their tasks and meeting deadlines, than they are with documenting decision processes. To capture and structure comprehensive project history is also inherently complicated, especially considering that the information must be easily retrievable later for it to have any value. To address these challenges Weiser and Morrison (1998) proposed to use an object-oriented data model where project information was decomposed in five classes, being projects, users, events, meetings and documents. The classes are indexed and can be retrieved using contextual information such as project reference, when the entry was created/modified, who created them, or by using user-supplied descriptive keywords. To evaluate the systems usability, Weiser and Morrison performed a field study where 24 undergraduate business students were divided in two groups. One group was trained and instructed to use the Project Memory system while the other group was instructed to work with the traditional paper-based system. The conclusion from the field study was:

- Without a reason to use the system actively, team members saw no added value over their present approach to data management
- Users need to use the system over time for it to become mission-critical, and that users ultimately will recognize the added value
- Little process and rational information were captured by members. One proposed strategy to overcome this challenge is to measure documented information progress as a project deliverable

It might seem obvious that IT systems are superior to paper copies for managing information, but the findings of the study are arguably more related to human nature, and our inherent resistance to change, than they are to the choice of information management system. For knowledge retention to be successful, employees must have a reason to use the system, they need time to familiarize, the system must be populated before it has any value, and people tends to not prioritize documenting decision processes. This is arguably just as relevant today if wanting to establish working methods for information retention and knowledge management. To motivate users to use the system, Weiser and Morrison identified six key factors:

- Familiar application environments - Users should be able to work in familiar application environments when creating documents and documents are automatically stored
- Standardized user-supplied key words - When a user needs to assign key words to a newly created document, a list of relevant key words should be provided to ensure consistent use of syntaxes. If a user needs to create a new key word it is added to the list and made available for other users
- Proprietary storage – To ensure data integrity a consistency, all files must be stored in the database
- Security classifications – To encourage users to submit work-in-progress and potentially sensitive information the system should provide selectable security levels for *personal*, *group* or *all*

- Multiple but contained access paths – To facilitate ease of access, for example in cases where users do not know what they are looking for, it must be possible to search information also based on metadata such as creator, creation date, project link etc.
- Document granularity – Each documents relation to other documents must be captured to avoid single documents being interpreted out of context

One should obviously not draw a conclusion based on one case study alone, but most of the factors listed above are key functionalities in COMOS, so if one were to side with Weiser and Morrison, the COMOS platform appears to be well suited for knowledge management purposes. However, as of today the COMOS platform in Aker Solutions is primarily used to document engineering data through system modelling and object attributes. Processes, context and product experiences are documented in a lesson learnt database but linking this information to the product and system is missing, and feedback from the interviewed candidates was that the lessons learnt process is flawed. “We have a significant improvement potential for recording and using lessons learnt. We often end up asking colleagues that have worked with similar topic before, what they did and what they remember” (candidate C, 2019). This view was also supported by candidate B who stated:

> The lessons learnt database contains much information, but the information tends to be hard to find. One alternative can perhaps be to establish rules (logic) in COMOS which identify and implement "best practice" design based on parameters such as water depth, XMT type etc. (candidate B, 2019).

In addition to the challenges with finding and using lessons learnt, several of the candidates also expressed belief that systems and application engineering is suffering from not having a unified engineering tool with library functionality. Per today, the disciplines are working with multiple software tools and the files are usually stored locally or on access restricted shared areas. Instead of using standardized “best practice” approach, engineers therefore tend to start from scratch or reuse by copy-pasting from old projects that the engineer is familiar with and have access to. In this context, object-orientation has a clear advantage for facilitating engineering reuse through its library functionality, where previously engineered object and systems can be easily reused (Karim & Adeli, 1999). Reusing engineering can reduce cost and schedule and contribute to improving quality. By standardize the system building blocks it is possible to have stocking programs and to improve quality through repetitive processes. Because it is naturally easier to achieve process improvements if one is working with the same things over and over. COMOS solve parts of this problem with its library functionality, but it would be an even bigger improvement if managing to connect the lessons learnt history with the object library. Knowledge management and engineering reuse are arguably closely linked, because reusing without understanding context and previous experiences can lead to critical mistakes. The importance of improving engineering reuse was highlighted by the interviewed candidates, to be one of the two biggest opportunities for reducing cost and schedule. The other was to digitalize controls engineering [ref. section 5.2]. There are obviously also pitfalls with reuse that must be considered. Such as the risk of reusing systematic errors which are not identified due to reduced focus on detail engineering, or incorrect reuse of previously validated solutions. To mitigate such errors, it is important to not only document the decisions, but also the thought process and discussions that led to the final design. Per today, the aspect of linking context and lessons learnt to equipment (objects) is not prioritized.

6 Conclusion

This paper concludes that object-orientation has significant potential towards achieving operational excellence in Aker Solutions' subsea business unit. Central is that the methodology offers a holistic information model where project and equipment data is stored in a single source database. This enables users to understand and communicate about complex systems more efficiently, both across disciplines and geographical locations. By automating manual tasks, facilitating efficient information flow and ensuring data consistency, project members can spend less time on administrative tasks and chasing information. This eliminates "waste" and improves quality. Besides, moving from a document-oriented to an attribute-oriented information repository is considered necessary for digitalizing engineering data. This paradigm change simplifies data exchange between software tools, allow for creating "digital twins" of hardware assets and offers better methods for reusing engineering and exerting project control.

The research found that object-orientation has several characteristics and functionalities that can improve project execution in terms of cost, schedule and quality, but the paper focus on four topics that are believed to be especially relevant. The topics are *digitalization*, *collaborative engineering*, *project control*, and *knowledge management and reuse*. While the study has focused on the case of Aker Solutions and their IT architecture, it is presumed that the benefits of object-orientation are equally relevant for other organizations. But depending on the nature of their business and IT architecture, there might be other software platforms better suited than COMOS. For Subsea, however, historical decisions have led to the present-day IT architecture and are limiting the decision window for choice of object-oriented software solution. To capitalize on the synergy effects of sharing engineering platform, resource pool and support organization with Greenfield, COMOS is the obvious choice. But that is not to say that COMOS could not have been the preferred solution regardless.

The study concludes that object-orientation has significant potential and that Subsea can learn a lot from Greenfield. However, the methodology must be adapted to Subsea's needs and it cannot just be a copy of Greenfield methodology, as the two business units and their challenges are too different. Furthermore, the implementation of COMOS is a major change initiative and should be treated as such. To capitalize on the full potential of object-orientation it is necessary to rethink and challenge subsea working methods, not just adapt COMOS to the "Subsea-way". This requires a change in mindset for the entire business unit and perhaps especially the engineering disciplines. This might be the initiatives greatest challenge. Besides, there are numerous ongoing change initiatives in Aker Solutions and it is considered important to align the initiatives, both against each other and towards the company's vision and road map for digitalization and improving work processes. This must be done to avoid parallel, overlapping or conflicting initiatives and to ensure optimal process outcome.

6.1 Recommendation for further studies

Research for this thesis revealed that there is a significant amount of literature focused on object-oriented methodology for IT development purposes, but it has been challenging to find research focused on object-orientation for non-IT project execution. Literature searches were primarily done through libraries, the Oria portal and Google Scholar, using numerous variations of search words and strings related to key words listed in the Abstract. Some articles were found, but several of the works are more than 20 years old, which raises the question of relevance. The lack of breath and depth in literature makes it difficult to conclude if object-oriented project execution is more efficient than alternative methodologies. It is therefore recommended that further studies are done to compare object-orientation against other methodologies, in the context of managing engineering data for project execution.

Furthermore, the research for this thesis has taken an exploratory approach, focusing on organizational and process aspect for *if* and *how* object-orientation can contribute to improve execution in Subsea. But the topics have not been evaluated in detail in terms of technical feasibility, process efficiency, or how to best integrate object-oriented methods and tools with existing ones. The interface between existing and new methods/tools is considered to be especially interesting, and it is recommended that further research is done to study these aspects.

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APPENDIX A – COMOS module description

COMOS Process

COMOS Process consists of the five modules COMOS FEED, COMOS P&ID, COMOS PipeSpec, COMOS Isometrics and COMOS 3D Integration. In the initial phase of a process plant study COMOS FEED can be used to create process flow diagrams (PFD's) and to establish rough cost estimates. These process flow diagrams form the basis for the system layout and for detailed piping and instrumentation diagrams (P&ID's). A library of process modules with drag & drop functionality allows for standardization and re-use, enabling users to create recurring sequences which meet their individual requirements. The program can automatically detect and identify inconsistencies in the design, if this functionality is activated, and once the PFD's are completed, all necessary data sheets and lists, such as general plans, material information, etc. can be automatically created.

If it is decided to proceed with detail engineering the process flow diagrams can be converted into detailed piping and instrumentation diagrams. P&ID's can be worked on bidirectionally and multiple users can work on the same diagrams at the same time. To ensure historic traceability all revision can be stored for later review. COMOS also offers a library of internationally standardized P&ID symbols and once a symbol is inserted, all the required connecting parts are identified and added according to the correct flow direction. To ensure consistent use of pipe specifications across departments and disciplines, COMOS PipeSpec offers a catalog of specs which are based on internationally validated standards, such as ISO, EN and ASTM.

Once the system layout is mature, COMOS Isometric can be used to create isometric drawings, and by utilizing the object-oriented database the isometric drawings can be automatically populated with necessary data from COMOS P&ID and COMOS PipeSpec. The isometric pipe layout can also be integrated with 3D modelling software, allowing for direct synchronization between COMOS P&ID, COMOS PipeSpec and the plant's 3D model. COMOS PDMS (E3D) Integration offers a built-in interface for AVEVA PDMS (E3D), a widely used 3D modelling software, but interfaces can also be established for other third party 3D software ("The COMOS portfolio", n.d.).

COMOS Automation

COMOS Automation consists of the two modules COMOS EI&C and COMOS Logical. Complex automations systems are in most cases required for operating process plants, and COMOS EI&C offers a software solution for detailing and specifying functional EI&C data which was schematically described during the process planning. These automation solutions can either be described in a single-lined (simplified) or multi-lined (detailed) representations. Same as for the other COMOS modules, COMOS EI&C also offers a library of standardized objects, with drag and drop functionality. It can also automatically generate required documents such as terminal diagrams, cable lists, parts and order lists.

COMOS Logical offer a solution for graphical creation of function plans and sequences in accordance with applicable standards. Here the information from the EI&C planning can be further detailed, relating to the number and type of signals ("The COMOS portfolio", n.d.).

COMOS Operations

COMOS Operations consists of the four modules COMOS MRO, COMOS Shutdown, COMOS Portable & Direct and COMOS Inspection. COMOS MRO (Maintenance, Repair & Overhaul) gathers all aspects of managing, planning and organizing operation and maintenance in a single system, including plant documentation. For an optimal maintenance regime, individual components can be risk analyzed in COMOS and evaluated according to different criteria. Maintenance can also be managed and notified based on condition monitoring or predefined maintenance/inspection intervals. All changes to the plant are documented in the system and are automatically available in the engineering data. This ensures that accurate and up-to-date information is available in case of future modifications to the plant.

During a plants lifecycle it can be necessary to shut it down temporarily, for example due to maintenance. Shutdowns often come with very high cost and a potential for risk to health and safety so effective and safe execution is crucial. For this purpose, COMOS Shutdown offers a solution to manage planning and execution of shutdowns by coordinating communication between all involved disciplines and departments. The functionality includes estimating, scheduling, coordination, progress assessment, reporting etc. After a shutdown is completed, COMOS Shutdown also offers functionality to evaluate the execution, with the intention to identify improvement potentials for future shutdowns.

COMOS Portable give users direct access to maintenance orders on handheld devices such as tablets and smartphones. Using RFID chips, the plant equipment can be scanned and identified on-site. With applicable documentation downloaded on the device the maintenance steps are available to the operator who checks them off on the device once completed. The status is reported in the system and become immediately available to planners and all other relevant users. COMOS Direct is designed for central feedback via terminal stations in the workshop or in the field using card reader or barcode scanners. The terminal interface displays only the current task to be processed by the technician that is currently logged in. He/she can make entries regarding time, material and maintenance directly on the terminal.

Using input from COMOS Isometrics, COMOS Inspection can determine and specify inspection points for scheduled measurements. These inspections can be included in COMOS MRO plans and measurements can be done on-site with mobile ultrasound or x-ray devices. Measured values such as the condition of the welded seams, corrosion, etc., are fed directly into the COMOS system via an interface and the input can, among others, be used for condition monitoring ("The COMOS portfolio", n.d.).

COMOS Lifecycle

COMOS Lifecycle consists of the three modules COMOS PQM, COMOS WalkInside and COMOS Mobile Solutions. COMOS PQM (Project Quality Management) is a document management platform for the plant, containing both documents created in COMOS and externally generated documentation such as Microsoft Office files. For traceability, COMOS PQM saves metadata for all documents, for example who created or modified the document and at what time it was edited. Once a document is formally released by the responsible user the original document is locked for editing and a PDF copy becomes available in the system. COMOS PQM also distinguishes between project documentation and latest revision as-built documentation which shall be used for plant operations.

To complement COMOS's data management systems, COMOS WalkInside offers a 3D visualization tool for the process plant, a digital twin, using 3D engineering data from the basic and detail engineering phases. The software offers virtual reality presentation (VR) and can for example be used in design and safety reviews, to facilitate real-time engineering collaborations, planning commissioning and maintenance or to train operators.

COMOS Mobile Solutions is a mobile platform which gives users on-the-go access to view and edit plant documentations. This enables user to work effectively while travelling and can provide great value for on-site follow-up of fabrication and modification activities. COMOS Mobile Solutions also provide suppliers with the opportunity to upload documents and edit data directly into COMOS ("The COMOS portfolio", n.d.).

APPENDIX B – Research results

Questions	**Candidate A**
In short, what do you believe are the biggest challenges the company needs to solve to achieve operational excellence*? (disconnected from COMOS)	• One challenge is the inefficient execution for MC and Completion, with significant amount of manually updating in multiple Excel spreadsheets. Is, however, unsure if COMOS is the right tool for improving working methods for these disciplines.
What are the most important challenges for operational excellence* that you believe COMOS can potentially solve? And how?	• Better information flow with same information instantly available to everyone. Earlier and formalized access to information, reducing information exchange verbally and via email. • COMOS integrates engineering for all system disciplines (controls, process, system etc.) where everyone works on the same object • Improves understanding through visualization • Fewer interfaces raised in the interface register • Value is greatest for engineering discipline • Product information is freely available to everyone, which can ensure earlier identification of discipline conflicts. More efficient 3D modelling because of earlier input. Less iteration. • Linking system and product. Specifications vs. product portfolio • Facilitate technical contract review where there is potential for improving. By specifying the system in COMOS and linking these to the product specifications in SAP we can automate deviation identification. Requirements vs. capacity • Improved project control and data/information consistency • Avoid yellow line checking with master data source. No duplicated information • More efficient LCI with automated document transmittals. A considerable manual task for Subsea, but which is automated in Greenfield
Can you say something about how you believe COMOS fits in with the company's existing systems? (SAP, 3D modelling, Primavera etc.)	• COMOS fits well with the company's existing systems and several links are already established. But it's not straight forward and especially the link with SAP is important and will require a lot of work to implement. • We have a way to go before information can flow automatically between the systems. • Aker Solutions is missing a systems tool, so Excel is widely used to list and exchange data. COMOS can fill a big part of this gap. • SAP is the master IT platform in Subsea and if future versions are more flexible and cost efficient to develop, COMOS might not be the right solution in long term. One does not want to spread object information unless absolutely necessary. • IT tools typically have a lifespan of 10 years. COMOS is a step in the right direction, but it's not necessarily the best long-term solution. It's the object-orientation methodology, not the tool, that's important.
Can you say something about how you believe COMOS fits in with the company's strategy for digitalization?	• Object-oriented tools are well suited for digitalization and linking systems is important. Greenfield has done this for 10 years, but Subsea is behind in this regard. • COMOS (object-orientation) focus on parameter information, while in SAP the information is stored on drawings and documents which cannot be automatically extracted and used in other systems.

What do you think about the possibility and benefits of integrating COMOS with procurement?	• Per today Procurement Tableau Dashboard, which is part of Project Management Dashboard, provides PO status, open PO lines etc., but it doesn't capture what information is required from procurement to progress with engineering. • By connecting PO's with the object one can run PO reports based on object status which would give better management rapports for EPC. • Request for quotation (RFQ) can be sent when key information is ready instead of waiting for the SAP material to reach Z9 status.
Which function and benefit do you believe COMOS can have for designing subsea controls systems / software?	• Controls often don't deliver interface information on time. With object orientation, everyone must exchange information continuously, even if it's not frozen. Improves collaboration. • Per today, our system engineering processes aren't adapted for software development. Minor changes to systems or equipment can lead to significant and time-consuming changes to the software. • COMOS visualize the system lay out in a good way which can potentially improve engineering and onboarding.
What do you believe will be the biggest challenges for implementing COMOS for Subsea? And how do you believe these challenges can be neutralized?	• Success will depend on everyone understanding the need for sharing and registering information, even if it's not adding value to own work. Following work instructions instead of "doing what I believe is necessary", which is a bit typical for Norwegians. • Management of change and change resistance – implementing COMOS (object-orientation) is a completely new way of working. Many will probably not understand the purpose and what it takes to harvest the benefits. COMOS is not just a new drawing tool, it is a database. • Will require big changes to the company's governance model. Larger organization where people need support and training means increased overhead cost. Where shall this cost be taken? This can be just as challenging as the technical part. • Need for a change in governance model applies both in the implementation phase and during execution/operation phase. • The value of object orientation will not be realized unless "done right"! This will require a lot of resources to archive. Quality of information is especially important for developing a «Digital Twin». • The construction business is way ahead of Subsea in terms of standardization and digitalization.
Do you see any differences between Subsea and Topside which can prevent efficient use of COMOS in Subsea?	• Subsea normally has five to six lump sum projects per year, compared to Greenfield who has one reimbursable project. This affects how the organization relates project execution overhead (governance). Greater overhead due to increased need for support functions and training. • Topside use COMOS as its primary project data hub. That is not natural for Subsea where SAP is the obvious choice. • SAP is not easily phased out but is challenged by being expensive and rigid. • It will be a big benefit to use a common data platform for executing integrated subsea and topside projects, such as Johan Castberg. Great potential for improving project cost by executing integrated projects due to reduced interface coordination and avoiding duplicated work.
What do you think about COMOS' suitability as a tool for traditional SPS	• COMOS have greater value as a tool for boosting and separation projects, compared to traditional SPS projects, due to more

projects, compared with subsea boosting- and separation projects where process engineering accounts for a larger portion of the engineering hours?	extensive system/process design, more similar to Greenfield. But there are also benefits for SPS projects execution which makes object-orientation the "way to go". • Aker Solutions needs to become more efficient, gain better control and deliver faster. COMOS can contribute to this. • SPS projects are being increasingly executed globally with deliverables coming from local hubs in all parts of the world. That means that live interface information needs to be available at all time in order to work efficiently, which is a strong suite for COMOS.
Engineering progress is to a large extent measured based on MDL-status. 1.) Do you believe that it gives a sufficiently good basis for project control to measure engineering progress this way? 2.) Can you say something about if/how you believe engineering can be controlled better by using COMOS?	• Engineering is per today measured based on MDL. With COMOS one can instead measure status based on control objects and information maturity. • It was previously believed that MDL documents accounted for 80% of the engineering scope, but we have now realized that it only accounts for maximum 50%. • With established links to the 3D software we can even measure engineering progress based on the 3D model maturity which would benefit engineering and project management control.
What are your thoughts on the importance and focus for documenting decision processes to facilitate re-use of engineering?	• Have strong belief in future improvements to engineering schedule related to reuse of engineering. Estimates that 1-2 months can be cut from the schedule if engineering is based on project layout templates from previous projects. This would be a significant cost/time saving. • Aker Solutions have improvement potential regarding knowledge retention. • Information is stored in COMOS, but decision history and know-how are collective memory among the engineers. • We should have ambitions to standardize more and do less product engineering, except for R&D of course.
How do you believe that implementing COMOS will affect Subsea PEM?	• PEM must highlight which products/objects that are most important. • Per today, PEM is based on document status with yes/no questions. Gate reviews are done two times per year and it's difficult to track the status between gate reviews. • With object-orientation the objects can be measured automatically and consistently, and PEM needs to be adapted accordingly.
What do you think about the possibility for using COMOS data established in FEED and project execution in the operation phase?	• Believe that COMOS will have greatest value for moving from FEED to EPC and that it seems unrealistic that operators will pay us to take control over their operation phase. It can, however, be a potential with AkerBP through the established alliance.

* The questions are formulated to be asked regardless of the interview objects role in the organization and "operational excellence" shall be interpreted as "optimal execution for the field/project/department the given candidate is responsible for".

Questions	Candidate B
In short, what do you believe are the biggest challenges the company needs to solve to achieve operational excellence*? (disconnected from COMOS)	• Not covered
What are the most important challenges for operational excellence* that you believe COMOS can potentially solve? And how?	• Have an ambition to improve efficiency for Front End work through automatically generated MEL and cost estimates based on drawn Field Schematics. For example, by drawing the field layout from riser to well, where COMOS can export object lists to Excel where detail lists for hubs, caps, valves etc. is generated based on logic functions. If linked to historic procurement data for price and lead time, this method can significantly improve cost estimate processing.
Can you say something about how you believe COMOS fits in with the company's existing systems? (SAP, 3D modelling, Primavera etc.)	• Believes, on general basis, that the software is not important, but how it can be used is! • Does not consider it as realistic that SAP is replaced, despite its weaknesses, because of what it would cost the company to change. Per now, COMOS is probably the best solution for filling the gaps.
Can you say something about how you believe COMOS fits in with the company's strategy for digitalization?	• To digitalize we are dependent on metadata and a good database. Drawings, procedures and documents in SAP contain "dumb" information that cannot automatically be extracted or searched. • This is solved with COMOS, where COMOS becomes the hub for connecting the information together. Just like for IoT, the technology is not very valuable before the different objects can communicate and interact.
What do you think about the possibility and benefits of integrating COMOS with procurement?	• If we want to achieve digitalization it is fundamental to also include procurement. • The goal should be to have a live information flow. In the beginning it is perhaps acceptable that information is updated once per day, but the target should be instant update of information being reflected in all systems. • It is not necessary to have Z9 status for sending RFQ's etc. We need to establish a more flexible process where activities can be initiated based on minimum required information, instead of having to wait for IFC documents.
Which function and benefit do you believe COMOS can have for designing subsea controls systems / software?	• Not covered
What do you believe will be the biggest challenges for implementing COMOS for Subsea? And how do you believe these challenges can be neutralized?	• Afraid that it will cost more than management expect, both cost and time, to get COMOS to work as we want. • Other industries are far ahead of the oil and gas industry with digitalization and it will take time for Aker Solutions to catch up.
Do you see any differences between Subsea and Topside which can prevent efficient use of COMOS in Subsea?	• Topside has come much further than Subsea with standardization which makes topside projects more suited for automated design processes. • It's important that COMOS is adapted to Subsea's specific needs, not just a copy of COMOS for topside. • SPS don't really need P&ID's for executing Front End or EPC, it's only the clients that needs the P&ID's. For SCS and Topside projects the system design is, however, depending on P&ID since it dictates the system requirements. • SPS are more challenged on cost than Topside are. For Topside (and SCS) it's more important to be "best in class". Unlike SPS,

	Topside and SCS normally work on reimbursable contracts where it's easier to get coverage for cost related to support function and training. That is important because a tool like COMOS will require more of this kind of resources.
What do you think about COMOS' suitability as a tool for traditional SPS projects, compared with subsea boosting- and separation projects where process engineering accounts for a larger portion of the engineering hours?	• Believes that COMOS is equally relevant for SPS as it is for subsea Processing/Boosting. Object-orientation is important for efficient FEED and EPC, but the choice of software is secondary. Most important is to have a database that can communicate with the applications that are used to solve the specific tasks. The company needs to have a clear vision and roadmap for evaluating which initiatives that are required and which software that are needed to fulfil the vision.
Engineering progress is to a large extent measured based on MDL-status. 1.) Do you believe that it gives a sufficiently good basis for project control to measure engineering progress this way? 2.) Can you say something about if/how you believe engineering can be controlled better by using COMOS?	• To measure engineering based on MDL can easily give misleading information. "Started" status for documents can for example be used to gain measured progress without any real progress to engineering. • To measure based on MDL is like chasing ghosts because status is outdated by the time the status is reported and analyzed. • On the other hand, the scheduled document IFC dates give a good indication of the requirements for the given document.
What are your thoughts on the importance and focus for documenting decision processes to facilitate re-use of engineering?	• There is a tendency for using junior personnel for drawing schematics, being repetitive and time-consuming work. This can be challenging because of the underlying complexity which drives the design. • The lessons learnt database contains much information, but the information tends to be hard to find. One alternative can perhaps be to establish rules (logic) in COMOS which identify and implement "best practice" design based on parameters such as water depth, XMT type etc. This could automate reuse of design.
How do you believe that implementing COMOS will affect Subsea PEM?	• PEM must be adapted to object-oriented methodology, but PEM as a tool will persist.
What do you think about the possibility for using COMOS data established in FEED and project execution in the operation phase?	• Large operators like Statoil, Total and Exon etc. will probably never hand over operational control, but smaller operators such as Okea, Vår Energi etc., which don't have large operations organizations, have express interest for outsourcing these activities. • Basis for Digital Twin

* The questions are formulated to be asked regardless of the interview objects role in the organization and "operational excellence" shall be interpreted as "optimal execution for the field/project/department the given candidate is responsible for".

Questions	Candidate C
In short, what do you believe are the biggest challenges the company needs to solve to achieve operational excellence*? (disconnected from COMOS)	• For system engineering one of the biggest challenges is the flow of information to the workpacks. Information such as system requirements which are described in documents created by system engineering is not satisfactory captured in the EPC phase. • Another challenge is the quality of, and time spent updating, "stupid" documents. If doing a change, one must remember to update all related documentation, such as MEL, valve list, drawings etc. • Wish that there was a graphic interface where one could find documents, for example by selecting a component and get access to all documents linked to that specific object. Information in SAP is hard to find, not easily searchable and it requires extensive training to navigate. This hinders efficient training and onboarding. Ideally there should be a project catalogue with a GUI where you can navigate through the hierarchy to find all relevant documentation.
What are the most important challenges for operational excellence* that you believe COMOS can potentially solve? And how?	• Another challenge is that we are working in too many systems that don't communicate, for example SWIMS. This leads to interfaces being created, but in reality, only being a request for information. This happens due to the challenge with finding information. Once created these interfaces needs to be monitored, answered, implemented, checked and closed. Adding a lot of additional work. COMOS can potentially solve this since information is more easily available for everyone. • Primavera and SAP does also not interact, which means that the schedule vs. engineering interface doesn't work as it should. Reactive instead of proactive control of engineering. We are always one step behind because the plan and the deliverables don't follow each other. • COMOS automate updates between systems/documents which should improve quality and reduce amount of manual work. • Hope that cap philosophy can be created in COMOS to automatically count caps based on logics defined for specific objects. This is currently a "stupid" but manually demanding task. • Reusing objects and models in COMOS should also reduce the work required for drawing system and field schematics. Potentially, one can draw a draft layout together with the client in a workshop, instead of senior personnel doing mark-ups that must be implemented and checked, one can update the drawings in COMOS directly.
Can you say something about how you believe COMOS fits in with the company's existing systems? (SAP, 3D modelling, Primavera etc.)	• We are working in many systems, for example doing documents and procurement in SAP, so it's important that COMOS can communicate with these systems. Uncertain how difficult it will be to establish these links. • Understand that the intention is for system definition to be done in COMOS, but product definition / design shall be done in PSM (SAP). These modules must be able to communicate and exchange information. But where shall scope control be done, COMOS or SAP? • We need a program to connect our stand-alone applications, but it isn't necessarily a goal for all information to be found in the same system. Instead it's probably better if the graphical interface directs the user to the applicable system and location where the information is stored.

Can you say something about how you believe COMOS fits in with the company's strategy for digitalization?	• Different disciplines don't usually need the entire document or drawing to proceed, but they require parts of the information captured in the document/drawing. The problem is that this information is not available until the document is issued for construction. We would probably have a smoother working process if we could connect milestones to parameters instead of to the documents. Also believes that we'd have better schedules by working this way, because it's more clear which information is driving the schedule • Believes that this can be solved through object-orientation (COMOS) and that going from information in document to information in databases is an important step for digitalization.
What do you think about the possibility and benefits of integrating COMOS with procurement?	• We have the same challenge with document vs. information requirement for procurement and one doesn't require the full documents for sending RFQ or placing the PO. Sees a need for assigning a maturity status for the information in COMOS so that users know how reliable the information is. This is important for a transparent collaboration environment in COMOS. • - It can be challenging that communication between engineering and suppliers goes through buyers, which doesn't necessarily have the same technical insight (Engineering is not good enough at explaining their requirements and procurements tend to work in silos). By working in the same environment, for example by giving suppliers access to parameters for their own equipment, we can potentially improve communication and reduce the risk of misunderstandings.
Which function and benefit do you believe COMOS can have for designing subsea controls systems / software?	• In COMOS one can assign logic elements to objects, which perhaps can be used for tying system/process/layout closer with controls. Improve understanding for relations and need for information. • By working in the same environment, controls can probably start their engineering earlier, based on information that is available in COMOS, even if not frozen.
What do you believe will be the biggest challenges for implementing COMOS for Subsea? And how do you believe these challenges can be neutralized?	• Believes that one of the biggest challenges is availability of competent resources with system understanding, who can work dedicated with the implementation project for COMOS. This is challenging because of limited resources which are already occupied with project work. • Another challenge is that we cannot expect that Topside COMOS will work "out of the box" for Subsea. COMOS must be specifically adapted because Topside and Subsea doesn't work the same way. We therefore need to map Subsea working processes to identify how COMOS can fill the requirements. • One step in adapting COMOS for Subsea is to adapt the attribute lists. By showing all attributes for an object we risk scaring users before they get familiarized. Propose to hide all irrelevant attributes. • Believes it's important to have good answers for what is the "value proposition" / benefit for using COMOS. Needs to clearly show what we want to achieve, so that users don't perceive it as yet another system that must be populated, in addition to everything else. This is important to neutralize change resistance which can already be felt in Jansz, despite the experience with COMOS from Åsgard.
Do you see any differences between Subsea and Topside which can prevent efficient use of COMOS in Subsea?	• Topside tags everything with functional tags, which we don't do in Subsea. It is important to "speak the same language" when discussing COMOS.

	• Topside is discipline oriented which is reflected in the user manuals. Subsea, however, work multidiscipline/workpack oriented. Working instructions for COMOS must be adapted to the Subsea way of working.
What do you think about COMOS' suitability as a tool for traditional SPS projects, compared with subsea boosting- and separation projects where process engineering accounts for a larger portion of the engineering hours?	• Uncertain how field schematics, which is the first step for any SPS project, is created in COMOS. • However, many of the other deliverables for system definition, top assembly, MEL etc., are similar for SPS and SCS. • Weight control is supposedly very efficient in COMOS (being done by topside) which can be a benefit for both SPS and SCS.
Engineering progress is to a large extent measured based on MDL-status. 1.) Do you believe that it gives a sufficiently good basis for project control to measure engineering progress this way? 2.) Can you say something about if/how you believe engineering can be controlled better by using COMOS?	• Believe that MDL is not a good indicator for engineering status. • Perhaps we can measure based on attributes with information that have a certain maturity level, parameter oriented. • Working hour requirements are also not representable from a planning point of view. For example, it can take 1000 hours to create a 3D model, but the progress is measured based on the drawing which takes 10 hours to make. Perhaps we can measure progress based on 3D model? • There are also aspects with measuring based on MDL with are unfortunate from a KPI perspective. Engineering cannot control DC or Client Review and it can be demotivating to be measured on something you cannot control. • However, how do you conduct client review if we don't measure based on documents but based on parameters? Perhaps clients also need to have access to COMOS?
What are your thoughts on the importance and focus for documenting decision processes to facilitate re-use of engineering?	• Believe that we have a significant improvement potential for recording and using lessons learnt. We often end up asking colleagues that have worked with similar topic before, what they did and what they remember. • We should document in COMOS, for example via an attribute or a note, which requirements that for the basis for the specific object/attribute/specification that is selected. This gives the option to gap analyze based on client specifications. • Probably don't need more than 1-2 sentences or a reference to a document for significantly improving decision traceability.
How do you believe that implementing COMOS will affect Subsea PEM?	• Believes that PEM adds limited value in its current form since the questions can be adjusted and interpreted. What adds value is the discussions that arise when PEM force people together to evaluate the status. • Milestones can perhaps be adjusted to reflect which information that needs what maturity level and measure based on parameters instead of documents/drawings that are IFC. • When only some information on a document/drawing is required it's easy, but risky, to underestimate the documents importance in a gate review if it doesn't meet the PEM gate requirement. • Perhaps PEM can communicate with COMOS and extract parameter status to automatically generate gate review reports? Information maturity is important.
What do you think about the possibility for using COMOS data established in FEED and project execution in the operation phase?	• No comment

* The questions are formulated to be asked regardless of the interview objects role in the organization and "operational excellence" shall be interpreted as "optimal execution for the field/project/department the given candidate is responsible for".

Questions	Candidate D
In short, what do you believe are the biggest challenges the company needs to solve to achieve operational excellence*? (disconnected from COMOS)	• Today’s oil and gas market is very competitive with high focus on reducing cost by being more efficient. This is necessary to enable passing of project investment decisions. Is especially apparent globally, but also in the North Sea. • Aker Solutions has come far in developing an international delivery model by connecting locations global sites. Examples are low cost engineering in Pune, fabrication in Malaysia and Brazil, and the new controls environment Reading, UK. However, multiple locations lead to an increase in cross-location interfaces which is challenging for achieving an efficient execution model. • There is also a need to influence the Operators. There is high focus on digitalization in the business, but we're missing a clear and unified direction. • We've come far, but there is still a significant potential for further optimizing working processes and cross-location collaboration. • Per the main challenge is to achieve efficient execution, rather than to offer new products. Believes that product development is moving towards standardization. Cheaper and quicker execution.
What are the most important challenges for operational excellence* that you believe COMOS can potentially solve? And how?	• Believe that COMOS has the potential to eliminate Excel engineering, which is standard practice in Subsea, but which impacts KPI effects and leads to poor communication. • Believes that COMOS has a good potential for reuse of project engineering, improve communication across locations and improve work process efficiency. Especially for the controls discipline.
Can you say something about how you believe COMOS fits in with the company's existing systems? (SAP, 3D modelling, Primavera etc.)	• IT tool interactivity is an interesting and important challenge. Developing the tool portfolio is a continuous process and engineering have historically had high focus on this. • In Subsea, SAP is used for most tasks, but SAP is not a very efficient tool. It's important to clarify what shall be done in which systems, SAP, COMOS, 3d tools etc., and how the systems shall be connected to exchange information, to capitalize on their individual and collective capacities. • Believes it's important to clarify how the tools shall interact before starting the implementation process. • We also need to consider that there might be new software products available, which are better suited, in just a few years. Need to design with flexibility. • Subsea has tended to engineer their own tools but believes that choosing commercial solutions is generally the best way to go.
Can you say something about how you believe COMOS fits in with the company's strategy for digitalization?	• COMOS is an important step towards providing a "digital twin” but is struggling to see the value proposition for a digital twin, compared to what we offer per today.
What do you think about the possibility and benefits of integrating COMOS with procurement?	• SAP is used for controlling manufacturing processes, warehouse and supply chain in Subsea. The interface between SAP and COMOS for these functions is very important, but we need to consider the cost-benefit. What we achieve and what does it cost to implement. It's easier to see the cost-benefit with COMOS for engineering. • Don't think it's realistic to phase out SAP
Which function and benefit do you believe COMOS can have for designing subsea controls systems / software?	• Believe that more efficient execution of controls engineering is one of, if not the, biggest potential with using COMOS in Subsea. This is critical for the success of the implementation process. I have the impression that controls engineering and work processes are

	outdated. Programming is done based on functional descriptions, something topside stopped doing 20 years ago. There should be great potential for using function blocks instead to develop controls systems. • Believe COMOS is well suited for controlling all the details (nitty gritty) required to design a functioning controls system. • Believe that the suitability for improving controls engineering is THE existential question for COMOS in Subsea. A quick win which can decide failure or success.
What do you believe will be the biggest challenges for implementing COMOS for Subsea? And how do you believe these challenges can be neutralized?	• Management of change is probably the greatest challenge. COMOS must be rolled out in a good way, which is challenging with many locations and subcultures. • Believes it's important that management clearly communicate to stop working "the old way" and that COMOS shall be used. Need to demonstrate the value of COMOS. • Implementing COMOS is a large and complex process which should be run as a separate project, with "the right people" onboard. • It also needs to be a technical feasibility certainty before starting the rollout. • Doesn't perceive that there is a clear understanding and awareness in the organization that rolling out COMOS is an important initiative right now. • It is a dilemma that for rolling out COMOS, many people must do more than they do today to get the system/process up and running, which can be met with resistance.
Do you see any differences between Subsea and Topside which can prevent efficient use of COMOS in Subsea?	• Believes that it’s easier to establish an understanding for why Topside needed a tool like COMOS because there is significantly more data required, but Subsea doesn't have the same complexity in terms of process and data engineering. Subsea is more product oriented, with less detail focus. This can make it more challenging to implement a complex tool, which COMOS is, in Subsea.
What do you think about COMOS’ suitability as a tool for traditional SPS projects, compared with subsea boosting- and separation projects where process engineering accounts for a larger portion of the engineering hours?	• For Åsgard, COMOS wasn't used in its full extent and Jansz has the potential to take it one step further. Believe controls is the key factor. • - It must be done a thorough evaluation, but if COMOS can give considerable positive effects for controls then it is worth implementing for SPS. There are, however, more synergy effects for SCS projects due to the connection with P&ID and process engineering.
Engineering progress is to a large extent measured based on MDL-status. 1.) Do you believe that it gives a sufficiently good basis for project control to measure engineering progress this way? 2.) Can you say something about if/how you believe engineering can be controlled better by using COMOS?	• Believes that measuring engineering based on MDL doesn't provide good control basis. • If possible to develop a better planning process by connecting the schedule to object parameter development in COMOS and 3D model status (like topside does), we can realize a considerable positive effect. Subsea is not good enough at planning, for example, we don't have detailed links between engineering and procurement. • Experience that we often start projects having considerable time for procurement, but always end up placing express PO's due to schedule constraints. • Controlling engineering is highly important. Errors done in engineering can have huge impact on cost and schedule delays in later phases. Unfortunately, we often end up doing firefighting to correct errors.
What are your thoughts on the importance and focus for documenting	• One of the purposes with SAP is to facilitate reuse of material numbers, using the same documentation etc. This intention is good

decision processes to facilitate re-use of engineering?	but is not sure if we are succeeding. There is a tendency to create new material numbers instead of reusing old ones. • Hope that COMOS can simplify and improve reused. Believes that successful reuse is critical for the company's competitive success. • Aker Solutions' newly developed XMT, which has been sold to several projects and clients, is a good example of standardization done right. • Believe it's important to make and implement good work instructions, which limits the options, to force reuse instead of re-engineering. The process is just as important as the tool.
How do you believe that implementing COMOS will affect Subsea PEM?	• We need to think about PEM in a different way in Subsea. It's unclear what PEM actually controls, besides the check points that specific activities have been done. • PEM can probably be improved significantly if being based on the type of working process methodology which COMOS can facilitate. • We are the moving towards Topside way of thinking and working, but we must not make the mistake of thinking it is the same. For Subsea, product delivery and standardization are critical, while Greenfield start from scratch every time, which we cannot allow ourselves in Subsea. • It is important to implement COMOS in Subsea, but it needs to be adapted to Subsea way of working.
What do you think about the possibility for using COMOS data established in FEED and project execution in the operation phase?	• Aker Solutions have personnel working on establishing and selling asset management services and there is a clear opportunity. We are however stepping in the hornet nest, operator's core competence, with many stake holders that have their own interests, traditions and tools. "Everyone" usually wants to own everything themselves and just hire in expertise when needed. To take a part of the asset management market we need to challenge and change this regime. • Believe that the collaboration agreement with Aker BP probably has the greatest potential in this context.

* The questions are formulated to be asked regardless of the interview objects role in the organization and "operational excellence" shall be interpreted as "optimal execution for the field/project/department the given candidate is responsible for".

Questions	Candidate E
In short, what do you believe are the biggest challenges the company needs to solve to achieve operational excellence*? (disconnected from COMOS)	• Compressions projects are hard because they are midway between Subsea and Greenfield in terms of working method and tools - support functions are either keyed against Topside or XMT type of deliveries. • We are one company but have two sets of toolboxes. Compression projects try to use both, neither specific for Compression, nor in worst case switching between different tools (f.exe. SW vs. PDMS) • Executing both subsea and topside project under same project organization
What are the most important challenges for operational excellence* that you believe COMOS can potentially solve? And how?	• Tagging is more complicated and of interest for subsea compression than for SPS. COMOS is a better way of managing tags than f.exe. Excel registers - avoid duplicates and manual updates (tag errors) • COMOS is a better scope management tool than SAP • COMOS ensure better information access. Its decided to not use SWIMS for Jansz. SWIMS don't have links to applicable documents or tags • SWIMS is often just used to exchange documents and information. Not very efficient • Ambition to limit interfaces on Jansz because information is widely available in COMOS - strict control for raising interfaces • COMOS is used to draw P&ID's, but we are not using the program to facilitate engineering, i.e. workflow coordination etc. (Won't work because we are measuring progress based on MDL and • documents will be in SAP)
Can you say something about how you believe COMOS fits in with the company's existing systems? (SAP, 3D modelling, Primavera etc.)	• It's a problem that COMOS is not very well integrated with SolidWorks and don't think that will ever happen. SW will be used in FEED but believes that E3D will be used afterwards. E3D is better suited for main steel and piping, with link to COMOS for tags etc., but is not suited for detail 3D models or machining drawings. Dependent on using both SW and E3D. • - Hopes that SAP (PSM etc.) can be integrated properly with COMOS, but that it's a process outside the Jansz projects control • - We need to execute PDMS (E3D) part smarter than we did on Åsgard
Can you say something about how you believe COMOS fits in with the company's strategy for digitalization?	• Believes the biggest potential is for Controls, which is currently being done in AutoCAD. If we can create Top Assembly which shows jumper level and define the jumpers with pins, we can hopefully automatically generate wiring diagrams etc. See question 8. • There are ongoing discussions regarding Digital Twin for Jansz, but nothing concrete
What do you think about the possibility and benefits of integrating COMOS with procurement?	• Link between COMOS and SAP is a big challenge. • Process data sheets will be in COMOS, but these need to be manually moved to SAP and there is currently not a big ambition to put the other documents in COMOS • For MN's you don't have a specific equipment until it's fabricated and assigned a serial number, unlike COMOS where you define and tag all items upfront
Which function and benefit do you believe COMOS can have for designing subsea controls systems / software?	• Believes the biggest potential is for Controls, which is currently being done in AutoCAD. If we can create Top Assembly which shows jumper level and define the jumpers with pins, we can hopefully automatically generate wiring diagrams etc. • Would also be good to create SCD's in COMOS. Won't necessarily help on Jansz since Yokogawa (SAS supplier for Jansz) don't use

	SCD's, but request narratives as basis for design. • With P&ID's and Controls drawings in COMOS we get integrated alarm lists, SCD's, control set points, cause and effect, wiring diagrams etc. = Less manual work. Computers make fewer errors. • There are ongoing discussions regarding Digital Twin for Jansz, but nothing concrete • There is a difference in how system engineering is done in the North Sea (++) or in Asia/Pacific: Suppliers like Aker Solutions and FMC does all the system engineering and tells Kongsberg/ABB/etc. what to do and they program the system. Asian suppliers like Yokogawa they just want narratives and cause and effects so that they can design the controls system.
What do you believe will be the biggest challenges for implementing COMOS for Subsea? And how do you believe these challenges can be neutralized?	• Other software is not adapted for integration with COMOS, unlike it is for Greenfield. How much value we can achieve from using COMOS is dependent on how good connection we can establish, especially for SAP • Define who needs access and provide training • Get people to see the value in COMOS and convincing them to use it because it adds value, instead of forcing them
Do you see any differences between Subsea and Topside which can prevent efficient use of COMOS in Subsea?	• One Company but with two sets of toolboxes • Greenfield and COMOS focus on tags, which Subsea does not • Greenfield doesn't use interface registers at all, everything is in COMOS - transparency between COMOS, document system (ProArc) and 3D tool (E3D). Subsea is moving in that direction, but we are not there • Positive is that COMOS is integrated with CCS, meaning that you can link tags where changes occur
What do you think about COMOS' suitability as a tool for traditional SPS projects, compared with subsea boosting- and separation projects where process engineering accounts for a larger portion of the engineering hours?	• The benefit of digitalizing controls is equally relevant for SPS • SPS will probably never change to E3D and SW can probably not be properly integrated with COMOS, which means that you lose functionality related to checking the 3D model, weight management etc.
Engineering progress is to a large extent measured based on MDL-status. 1.) Do you believe that it gives a sufficiently good basis for project control to measure engineering progress this way? 2.) Can you say something about if/how you believe engineering can be controlled better by using COMOS?	• Believes that measuring on MDL isn't a good way to measure engineering. MDL document numbers change, documents are merged, split, voided etc. This is a bigger problem for lump sum projects than for reimbursable projects. • Don't have a good way to measure 3D model status/progress. Is basically done in design reviews, but its long periods between and done give enough information. Topside has more ways to measure on 3D model • Not currently any ambition to change how we measure progress, f.exe. based on parameters, in Jansz • Topside can better track the 3D model and status setting, adding better granularity to the progress report method
What are your thoughts on the importance and focus for documenting decision processes to facilitate re-use of engineering?	• It's probably easier to standardize for SPS than for compression projects. • Design in much more driven by field layout, reservoir conditions and process requirements • There is an ambition to reuse Åsgard documentation, but seemingly Chevron have very different requirements and preferences that what Statoil had, which makes it challenging • Chevron is not part of DNV standardization JIP which has been

	running, so they don't necessarily accept commonly agreed standardizations. Chevron upper management push cost savings, but discipline leads insist on their standard requirements
How do you believe that implementing COMOS will affect Subsea PEM?	• Topside is more data input driven, while Subsea is all about document status
What do you think about the possibility for using COMOS data established in FEED and project execution in the operation phase?	• For Åsgard, Statoil received a "smart" PDMS models containing all tags, line numbers etc. Information from COMOS which was embedded into PDMS. This was a contractual requirement and Jansz will probably have a similar requirement.

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Questions	Candidate F
In short, what do you believe are the biggest challenges the company needs to solve to achieve operational excellence*? (disconnected from COMOS)	• Believes that simplification and standardization of our product offering are important factors. • We need to move from "design to deliver" to "configure to deliver". Meaning that we don't start with a clean slate and considering all alternatives. "Configure to deliver" means instead to see how we can configure our products to meet the customers’ requirements. • Another aspect is to connect the system and the products (objects), but that is implicit in "configure to deliver". • We also need to break down barriers. We have a structure where Systems engineer the system and workpacks deliver the hardware, but Controls which is a critical part of the overall system design is not included, instead designing their controls system and delivering the hardware independently. To re-integrate Controls with general system and hardware execution is fundamental.
What are the most important challenges for operational excellence* that you believe COMOS can potentially solve? And how?	• Believes that COMOS is a good tool for integrating controls system design with process, via the P&ID, which removes inconsistencies in the design. If everyone uses it. • By creating an object structure that matches our products we can standardize the system building blocks. This not only improves cost and lead time, but it also makes it possible to have stocking programs and to improve quality through repetitive processes. It is easier to achieve process improvements if working with the same things. • On important aspect with object-orientation is that there is only one data source. This avoids duplicated information and ensures consistency. One example is that documentation, such as P&ID, valve lists etc., are just report from the object database and changes are automatically reflected in all systems/reports. • Data consistency and efficiency though data consistency are key factors! • Per today we have many software tools for configuring and modelling equipment, but we are missing a program to tie it all together and configure the system. COMOS can potentially solve this.
Can you say something about how you believe COMOS fits in with the company's existing systems? (SAP, 3D modelling, Primavera etc.)	• COMOS primarily cover system engineering and it must be integrated with our software portfolio, SAP, SolidWorks etc. For example, that we have the same object hierarchy established in COMOS, in SAP and in SolidWorks. Meaning that our systems are mirrored and connected to with each other. • Ambition is that objects in COMOS are connected with SAP to link relevant documentation, part numbers, procurement information such as cost etc. • COMOS, as I see it, shall not replace SAP etc. It shall replace Excel spreadsheets and "flat" schematic drawings (controls schematics, top assembly, valve lists etc. etc.). All these lists and drawings are spread in systems that are not linked. Meaning that if someone adds a component in system design it is almost random luck if the change is captured in all applicable documents and drawings. • On important factor for successful implementation is that no one is allowed to continue working with parallel systems. Only connected system tools are allowed.
Can you say something about how you believe COMOS fits in with the company's strategy for digitalization?	• COMOS is the hub for the information hierarchy, which is digitalization. For the Jansz subsea compression project there is an initiative to digitalize all authoring systems. Per today we have not had a link between COMOS and SAP, which is important because

	SAP is where product information such as bill of material (BOM) is found. But we haven't had a system engineering tool, so to link the two means that we can maneuver throughout all the information categories in the different systems (schedule, procurement, documentation etc.). COMOS is the program that connects all the other data bases. • In context of digital twin, we need to evaluate how object-orientation/COMOS affect LCI. If we still need to deliver "flat" drawings, we are destroying the digital value that we've built up. To succeed it's not enough to work technical, with IT and system engineering, we also need to consider how this effects LCI, contract and intellectual property (IP).
What do you think about the possibility and benefits of integrating COMOS with procurement?	• By having an SAP-COMOS links we can see procurement status on an object level. For example, do we have a firm quote or just an estimate? This information should be visual in COMOS. • If we say that COMOS is the true data source where all the objects are, then changes to the system design can for example be used to automatically update procurement scope in SAP (or MIPS). This ensures that we don't procure materials we don't need etc.
Which function and benefit do you believe COMOS can have for designing subsea controls systems / software?	• Improving how we execute controls engineering and connecting it with the topside SAS is one of my main focus areas. • Topside projects use system controls diagram, controls loop diagrams etc. which specify how each controls loop shall be. Typically, an instrument is an object with attributes, but in Subsea it is just a part number. Through COMOS any sensor is assigned applicable alarm signals and control loops, building up the full automation system. By using this functionality, we can solve what has always been a problem in Subsea, namely the integration with the topside control system. • Per today we have cause and effect in Subsea, but otherwise we primarily describe the functionality with words. By starting to use block diagrams, SCD, loop diagrams etc., we use the "tribal language" that topside controls suppliers use. Allowing them to more easily being able to select the correct software blocks for designing and integrating the systems. • Aker Solutions is currently working with ABB to create smart SCD's to auto-generate SAS software code. SCD's are the tribal language, meaning that SAS supplier like Siemens, Honeywell or ABB immediately recognize what type of software blocks they will need to accommodate the specific controls system design. In the future, perhaps we can use SCD's from COMOS to automatically create SAS software when working with ABB? Through COMOS object parameters we would then have almost real-time software generation for the SAS system.
What do you believe will be the biggest challenges for implementing COMOS for Subsea? And how do you believe these challenges can be neutralized?	• We have now done the data technical work to connect SAP and COMOS, but there is a way to go to align the methodology (PEM). We need to think differently than what we have done before. • Believes that the traditional execution structure in Subsea, with workpacks, is a challenge. Is afraid that people don't understand what COMOS (object-orientation) is, or why we need it. To be successful the disciplines are required to work together, but historically the different departments in Subsea, system, products, projects, have worked separately.
Do you see any differences between Subsea and Topside which can prevent efficient use of COMOS in Subsea?	• Other than that topside projects are functionally much more complex, the main difference is that topside use a location tag methodology since they know exactly where specific equipment shall be located. In

	Subsea it is difficult to use tag numbering because of interchangeability requirements. Subsea needs flexibility because an XMT shall for example be able to be installed on any of the given production wells. • Believe that it is possible to find solutions to this problem, not allowing it to be an excuse for delaying implementation of COMOS.
What do you think about COMOS' suitability as a tool for traditional SPS projects, compared with subsea boosting- and separation projects where process engineering accounts for a larger portion of the engineering hours?	• Believe that SPS have at least equal benefit from object-orientation as ASP, by allowing standardizing of system engineering and schematics by using standard objects. Facilitating for quality improvements etc.
Engineering progress is to a large extent measured based on MDL-status. 1.) Do you believe that it gives a sufficiently good basis for project control to measure engineering progress this way? 2.) Can you say something about if/how you believe engineering can be controlled better by using COMOS?	• To just measure based on MDL is not good enough. Many of the schedule activities are not linked to documents, perhaps only 30-40%. That makes it difficult to control progress mid-ways. Alternatively, you can break down the activities and create intermediate documents. That gives high document coverage per activity, but you end up having a large number of documents which you really don't need. • To measure only based on documents only covers parts of the scope. This is a bit old-school. Historically a project only required document (drawings, calculations etc.), but with object-orientation we are building up the model, population information and making the model increasingly more mature. Perhaps it is then more relevant and important to have input control, rather than output control. With COMOS the drawings, tables and datasheets are output reports which are automatically generated from the model. • With output driven execution it is difficult to update changes in all systems, but this can be ensured by having a fully connected system. We can measure progress based on 3D model maturity. Even if the 3D model looks complete, the status might be different. For example, if HAZOP has been done for some components but not for others. This can be monitored by setting status on object level, allowing for measuring progress on objects instead of "dumb" documents.
What are your thoughts on the importance and focus for documenting decision processes to facilitate re-use of engineering?	• Covered in other replies to other questions.
How do you believe that implementing COMOS will affect Subsea PEM?	• It's been a while since working with PEM, but previously each WP had separate PEM. That is a contradiction since PEM shall be the framework for how to work together. By splitting PEM in several parts, you end up in a situation where, for example, the manifold can have status as completed, even if HAZOP or final calculations haven't been completed for process. This happens because the relationship links between the activities are missing. Hopefully this is better now. • In topside, which has a more mature PEM, they don't have several workpack. Instead they have two main things, the schematic and the 3D-model. These need to be linked, but if you have a PEM that details how to complete the schematics and a PEM for the 3D model, then you won't end up with activities being completed before their proceeding activities.
What do you think about the possibility for using COMOS data established in FEED and project	• It is obviously an opportunity for Aker Solutions to develop a service offering for managing the life cycle data model for our clients. When we manage to link COMOS and SAP, we have an integrated data

execution in the operation phase?	registers with one true data source and without duplicates. The challenge is to combine our information registers with our clients' and other contractors' data. If this information is spread over multiple platforms it is difficult for our clients, so: 1.) we need to gather the information and 2.) offer a digital platform where our clients can access all information in one system. A pump is a pump regardless of project or field and we can for example create a maintenance application for all the clients' pumps. If we manage to establish this kind of data platform, we can offer applications for maintenance, condition monitoring, training, handbooks etc. By "washing" the information and putting it in context we can create value for our customers. But we need to prove through a concrete project that we can deliver a digital twin that works. It is a lot of work to be done here. • It is on us to showcase to our clients the value we can provide through a digital twin offering. It is naive to think it is only technical interest that drives this. The clients want to know what they gain by giving us access to their condition monitoring data etc. Do we give them an extended warranty period for example? As a contractor we need to understand what it means to contract and liability to take responsibility for operation activities.

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