University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/Specialization: Industrial Asset Management	Spring semester, 2021 Open / ~~Restricted access~~
Writer: Petter Dyngeland Senum	…………………………………………… (Writer's signature)
Faculty supervisor: Jan Frick External supervisor(s): Emilie Houge Øritsland, Jawad Raza	
Thesis title: Market-analysis of software for PdM-solutions in the Norwegian petroleum industry	
Credits (ECTS): 30	
Key words: Predictive maintenance, business models, software solutions, market analysis	Pages: ……72……… + enclosure: …91…… Stavanger, 15.06.2021 Date/year

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Master thesis

Market-analysis of software for predictive maintenance solutions in the Norwegian petroleum industry

By

Petter Dyngeland Senum
233924
M.Sc.Industrial Asset Management

Master thesis written as a part of the Master of Science program Industrial Asset Management at the University of Stavanger

(Spring, 2021)

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Abstract

The Norwegian petroleum industry is currently undergoing a drastic technological change, often termed Industry 4.0. With this change, new innovative capabilities emerge across all operations and disciplines. Predictive maintenance is one of these. Well-functioning predictive maintenance solutions will potentially create substantial value to operator companies. However, accompanying technological innovations are some significant challenges. Especially considering the compliance between suppliers of software solutions and the end-user. This thesis investigates the current market of software for predictive maintenance solutions available in the Norwegian industry. The objective of the thesis is to attain a comprehensive understanding of compliance between end-user and supplier, and the emerging opportunities in the market. Currently, predictive maintenance is a hot topic in the industrial context. Yet, there is a lack of information regarding the industry-specific business perspective that this thesis addresses, making it an important addition to the field.

Based on literature review and informal talks with various relevant people from the industry, a series of semi-structured interviews with end-users and a regulatory agency is conducted. Further, based on the findings from the interviews, and some unstructured meetings internally in Apply and with supplier companies, one ideal- and one generalized business model canvas are developed. A comparison of these in addition to in-depth analyses of the interviews and the literature review makes up the data analysis for this thesis.

The analyses led to a series of interesting findings. Primarily there are some fundamental gaps between the ideal and generalized BMCs. Specifically, the allocation of resources and activities, together with a market definition. Further, there is deviating recognition on the importance of aspects like industrial references and certain attributes of the PdM solutions.

Looking at the entire market in terms of the findings, some prominent opportunities are emerging, especially for Apply and similar engineering companies. From the end-user's perspective, the PdM solutions should be developed internally by the engineering companies that already hold the experience and expertise necessary. Apply holds a solid position with promising potential to utilize the commercial opportunities.

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Acknowledgements

Throughout the writing of this thesis, I have received a great deal of support and guidance.

First, I would like to show my greatest gratitude to my supervisor, Professor Jan Frick, whose expertise and guidance have been of tremendous value. The insightful and experienced feedback contributed by professor Frick has inspired me to bring my research to a higher level.

Further, I would like to thank my external supervisors in Apply, Emilie Øristland Houge and Doctor Jawad Raza. You have been essential for the thesis to progress and attain its findings. I am truly grateful for your thorough support and supervision.

Next, many thanks to the employees at Apply for welcoming me and being of assistance whenever. Your kindness and generosity have made this semester a true joy.

I would also like to acknowledge all those who have participated in interviews, meetings, and other discussions. Your enthusiasm and cooperativeness have made the research uncomplicated and fulfilling.

Finally, I would like to show my appreciation to Apply who made this thesis possible, and to the University of Stavanger for providing me with a valuable, rewarding, and relevant education.

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Glossary

Abbreviation - Explanation

AI - Artificial Intelligence
BMC - Business Model Canvas
CapEx - Capital Expense
CBM - Condition-Based Maintenance
CM - Corrective Maintenance
CM - Condition Monitoring
CMMS - Computerized Maintenance Management System
DOS - Digital Operations Services
ERP - Enterprise Resource Planning
FTE - Full-Time Equivalent
I4 - Industry 4.0, The fourth industrial revolution
IIoT - Industrial Internet of Things
IoT - Internet of Things
IT - Information Technology
ML - Machine Learning
MaaS - Maintenance as a Service
NCS - Norwegian Continental Shelf
O&G - Oil and Gas
OpEx - Operational Expenses
OPS - Operations, Products and Services
OT - Operational Technology
PdM - Predictive Maintenance
PM - Preventive Maintenance
PSA - Petroleum Safety Authority
R&D - Research and Development

Chapter 1

Introduction

1.1 Motivation

At some point, all machines break down. This is a common industrial interpretation of a slightly different quote from the late British economist John Maynard Keynes (Keynes, 1924). The logic here is quite simple, yet it continues to represent the immense challenges for anyone operating assets in modern times. However, it has not always been that difficult. Maintaining equipment and machines just a few decades ago were not necessarily too problematic or challenging. Though, sometime during the 20$^{\text{th}}$ century, technology had developed so far that repairs were no longer straightforward jobs. For the machines with increased complexity, the job of maintaining them became way more advanced than the simple effort it had been before. With the third and fourth industrial revolution, technology complexity surpassed the cognitive capabilities of the human brain, resulting in people being inadequate on their own. Luckily, a way to cope emerged. It turned out that the very technology that outperformed people could be used to get them back on top. Currently, people rely on machines to help fix other machines.

The entire industrial environment is currently experiencing an ever-accelerating flow of technological innovations that utilize opportunities that, not too long ago, were far beyond reach. The fourth industrial revolution is ongoing and is influencing many parts of our lives, from the way people communicate with each other to how ads are targeted online. Further, the industrial aspects of Industry 4.0 carry a lot of potentials.

Industry 4.0 has influenced a vast spectrum of sub-fields in the industry, including maintenance. Maintenance has been revolutionized by technological innovations like sensors for condition monitoring and new tools and techniques for inspections. Despite this, the great potential of industry 4.0 technologies has not yet had the enormous impact on maintenance as expected. In other words, it seems that Industry 4.0 has unrealized potential in maintenance. One of the areas with less than anticipated effectiveness and impact is predictive maintenance and accompanying artificial intelligence for data analytics. While artificial intelligence capabilities have become much better in the last years, and become more common to be applied in many sectors, it has yet to attain the major benefits of it in industrial maintenance. For quite some time, promises have been made that the technologies related to Industry 4.0 will provide predictive capabilities for maintenance management with extremely high accuracy. Failures that before were understood be to inevitable would soon be foreseen and avoided. However, even though the technology has come far, its applicability for certain areas seems to be lagging.

This raises a question on whether or not this technology really is as groundbreaking as many persuade us to believe. If Industry 4.0 with its artificial intelligence, machine learning, data analytics, and cloud computing were as capable as its reputation would have us believe, would it not be much easier to solve all these challenges of predictive maintenance? As it turns out, it is not that simple. There are many other factors than purely the technology that affects the success of innovation in the modern industry which is characterized by high complexity. In this complex industrial environment, companies are dependant to adapt quickly to change. As a result, the strategies of companies today differ strongly from those just a few decades ago. New activities, partnerships, and customer expectations are just some of the areas that have undergone extensive innovation and modification. Ultimately, this forces companies to modify their functions, mindset, and approach in many areas. In turn, this basically means that the overall business model of companies must comply with the technology development for it to meet its potential. The question then becomes to what degree and in what way can the sub-optimized impact of predictive maintenance be a result of poor business models. In other words; are there areas of unrealized potential in the business models of industrial predictive maintenance?

Even though the oil and gas industry has been extremely valuable and profitable for Norway ever since its beginning some 50 years ago, optimization and productivity improvement are always something to aim for. With the last few years being heavily impacted by a lower oil price than before, the significance of optimizing and cutting costs is more important than ever. Maintenance traditionally makes up for a large portion of the overall costs related to big industrial assets, which are common in oil and gas. In 2020, there were 90 fields producing oil and gas. The related operating cost of these was about 60 billion NOK, where work related to maintenance makes up for about 15 billion NOK (*Investeringer og driftskostnader - Norskpetroleum*, n.d.). Considering that this industry has been strongly influenced by major challenges and crises over the last couple of years, an introduction of a well-functioning combination of the business model and predictive maintenance that will reduce cost and improve reliability at the same time will be greatly appreciated.

As mentioned, the current industrial environment is highly complex and fast-moving. This results in information being quickly outdated. Nevertheless, there are lots of valuable information in understanding how the development works. To attain a sufficient understanding of the technology, the business context, and their influence on each other to properly describe the overall quality and completeness, a combination of several methods must be applied. For this thesis, the methods will consist of semi-structured interviews with relevant personnel, unstructured meetings internally in Apply and with suppliers, a literature review, and workshops with relevant and experienced personnel within fields such as business development and maintenance management.

Given the limitation of time and other resources for this thesis, it will be delimited to focus primarily on the business models of predictive maintenance software for the oil and gas sector located on the Norwegian continental shelf.

The thesis will follow the standard structure and time period of most master thesis's related to the faculty of natural sciences at the University of Stavanger. The thesis is initiated by and written with Apply AS during the spring semester from January to June 2021.

1.2 Background and problem description

As described in the previous paragraphs, the industrial potentials of predictive maintenance are enormous. These have been researched through and through over many years. Currently, there are loads of companies claiming to have cracked the code and figured out how to efficiently and accurately apply artificial intelligence through machine learning and data analytics to deliver reliable predictive maintenance capabilities. However, these products and services have yet to succeed in terms of usage and customers.

It is not solely the technology itself that decides whether or not a product becomes a success, the business model it follows is also crucial. Examples are found throughout the entire human history but during the past couple of decades, this has become even more evident. Google did not revolutionize business models, but their two-sided platform worked well with their technology, the same goes for Ebay.com and Facebook (getsmarter, 2018). There is plenty of literature on how business models should be developed and modified. Yet, there is much less information on how these two fields influence each other, especially when focusing on industrial predictive maintenance as the technology. This thesis will investigate exactly how the business model interacts with industrial predictive maintenance products and services and unveil if there is any unrealized potential in the market for PdM partly through investigating business models.

Apply AS is already heavily involved in industrial maintenance on the NCS (Norwegian Continental Shelf) and is therefore naturally interested in ways to improve maintenance systems. One of their core values describes how Apply will work on being open-minded, embrace new challenges, think outside the box, and create innovative solutions for the future (Apply, 2021a). This correlates well with this field of study and subsequently this thesis. Predictive maintenance is an innovative technology that could help enhance the overall performance of service companies, such as Apply, but due to the many complex challenges, it has yet to reach its full potential.

Building on this, this thesis will not only analyze the currently available products and services for industrial predictive maintenance in terms of the way they exploit the potentials of well-combined technology with the business model but also how Apply as a service company working on the NCS could further initiate its efforts on this field coming years. The main focus of the thesis will be on the software solutions of industrial predictive maintenance.

1.3 Objective and research questions

As seen in the previous sections, this field of study has many challenges as well as many benefits and solutions. This thesis will apply a focused scope to reach the depth needed to comprehend the complexity of these challenges. Therefore, a concise and concrete overall objective must be defined together with some underlying and complementing research questions to set a reasonable framework for the thesis. The overall objective of the task is used to set the course of the entire research, and will briefly explain the main challenge to investigate. The following research questions will help to further explain and delve deeper into the field of interest to address the most important sub-challenges of the objective. For this thesis, the overall objective will be to:

Analyze the market for software solutions for predictive maintenance currently available for operators in the Norwegian industry, especially by investigating the business models for suppliers and their compliance with the attitude and perspective of end-users. Identify and explore challenges in the market, and suggest solutions to addressing them.

The thesis will mainly focus on the software solutions that are used in predictive maintenance for industrial companies operating on the NCS.

Considering the span and complexity of the objective, it becomes evident that there are numerous ways of addressing it, all with differing interests. The maintenance systems in this type of industrial context often consist of several companies, all with differing strategies, interests, and value propositions. Despite these dealing with the same overall challenges, their perspective will strongly influence how they perceive the challenges and subsequently affect their corresponding interests. Building on this, for the thesis to remain consistent in its reasoning and not have contradictory reasoning and subsequent findings or conclusions, a firm perspective must be consequently defined. Given that Apply wishes to investigate solutions that will benefit their customers, it is in their best interest to look at the challenges from an end-user perspective. This will provide valuable insights into how the services and products actually function for the customer and thereby unveil typical issues and tendencies in the current solutions on the market. At the same time, it is necessary to understand how the PdM software is structured and why it is developed in the way it is. Thus, exploring the software supplier´s strategic business models will also grant valuable information on the bigger picture, which comes in handy in this complex landscape. The research questions are therefore defined to be:

1. What is the view on PdM-software from the perspective of Asset Managers as the end-user?

2. Investigate the business models of PdM-solution providers. What are their main characteristics?

3. In terms of compliance between end-user needs and marked supply, which areas have good covered and which have gaps?

4. How can the findings be utilized by the industry?

To answer these questions in both a systematic and systemic fashion, a proper breakdown of the thesis structure is helpful to identify what should be included, how the chapters should be organized, and how everything fits together. Figure 1.1, shows how the objective and the following research questions fit into the various chapters of the thesis.

1.3.1 Author's role

When writing a report, article, thesis, etc., the role of the author will strongly influence the perspective and angle of it. The type of role varies from different types of research methods and their corresponding perspective of the research field. If, for instance, the data basis for a report is exclusively a literature study, the role of the author is as an observer. When conducting research from an observer's role, the research is less biased in terms of focus and objectives.

In action research, the researcher, or author, has insight into the inner workings of the case in question. The research has access to information that is not publicly available, and thus often is raw data not previously studied. In addition, the researcher interacts with the people involved and thereby attains data tailored for their specific research objective. (Reason & Bradbury, 2008)

This thesis can be described as a variation of action research. The researcher has been included in Apply's organization. Through this, the researcher has had access to relevant personnel and information that has complemented the basis of the thesis. In addition, the researcher has participated in meetings, both internally in Apply and between Apply and partners and suppliers. Further, the researcher has utilized the network of Apply and its employees to get in contact with relevant external personnel. This was particularly used to find relevant personnel in operator companies and in a government agency to interview as a central part of the data collection.

The role of the author in this thesis has affected the perspective and aim of the thesis, central parts of the data collection, and the general framework for the research. By having an active role in Apply, the author has gained valuable information on how decisions are made and processes developed, not just how they turned out. Apply has also had an impact on the structure and objective of the thesis.

1.3.2 Breakdown of thesis

In figure 1.1 the structure of the thesis is illustrated in the form of a flow chart. The boxes represent different central areas of the thesis. The boxes are sorted into vertical groups by their characteristics. As we move from the left to the right in the figure, we move through the processes needed to go from the overall objective of the thesis to the observations and corresponding conclusions.

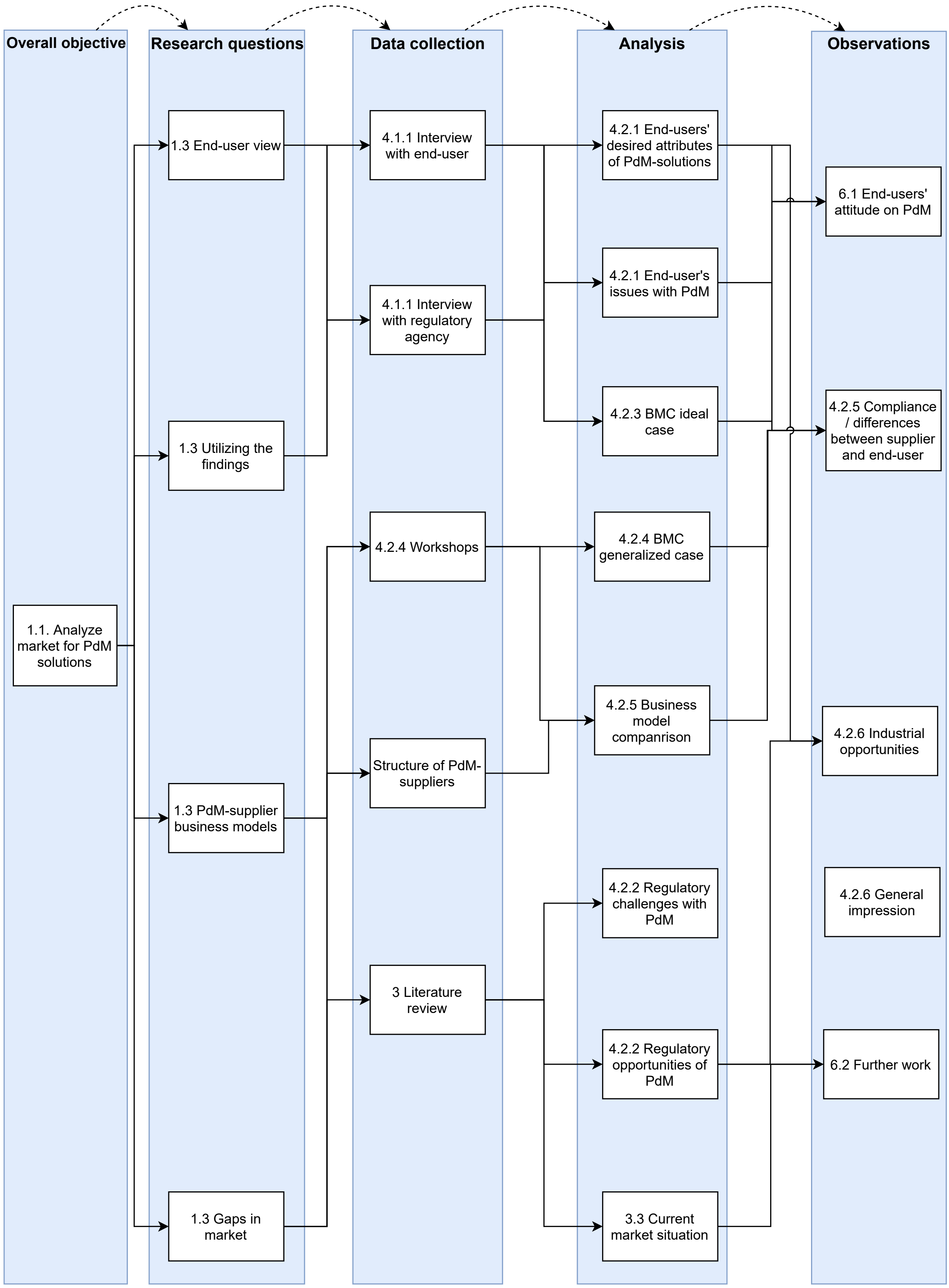


Figure 1.1: Overview of the thesis' process of flow and linkage from objective through to observations. (Created by author).

1.4 Apply

1.4.1 Apply - A brief introduction

Apply is a Norwegian engineering company operating in the oil and gas sector on the NCS. Apply's head office is located in Stavanger. Apply also have offices in Bergen and Hammerfest, in addition to a subsidiary in Krakow, Poland. Since its establishment in 1979, Apply has grown into a large engineering company on a Norwegian scale, currently employing about 1200 people (Apply, 2021b). In its beginning, the company provided engineering design to the oil and gas industry, and has since expanded to providing complete turnkey projects for maintenance, modifications and operations support contracts for both onshore- and offshore facilities (Apply, 2021a). Apply's vision is divided into four parts; Dynamic, Passion, Attentive, and Integrity

Apply is organized in a typical function-based structure with a chief executive officer at the top of the hierarchy and subsequent senior management with corresponding departments. Three business areas, and where each is divided into three main business units based on various fields. These are Maintenance & Modification, Front End & Green Solutions, and Operations, Products & Services. The latter, Operations, Products, and Services, supply Apply's customers with best-practice solutions for their assets. These products and services are addressed to the operations throughout the asset's entire life cycle. This business unit is further divided into more specific areas of expertise, one of which is Digital Operation Solutions, or DOS for short, which is the facilitator and initiator of this thesis.

1.4.2 Apply's intention with this thesis

Apply wants to unveil potential gaps or unrealized potential opportunities in the predictive maintenance segments that could be exploited. Hence, areas of potential improvement that Apply could use to their advantage. Given that this thesis is a part of Apply's DOS department, which is a part of the Business Unit OPS, there is an expectation and desire that the area of focus should be on the software and their business models.

1.4.3 What are the expected outcomes of the thesis?

Being an acknowledged and strongly positioned engineering company in Norway, Apply has a responsibility to all its stakeholders to remain at the forefront in its field. This means that Apply must assign resources in other areas than solely their current contracts to keep their competitive position in the industry. Among other initiatives, this includes exploring the possibilities surrounding predictive maintenance. New solutions are being launched regularly, and with these new innovative technologies rises the expectations of end-users. Currently, there are many solutions on predictive maintenance available for the Norwegian industry. If these can contribute to improving Apply's capabilities they are of great interest. Nevertheless, engineering and service companies must choose an approach to this very interesting and potentially valuable technological innovation. Through this thesis, Apply wishes to gain a comprehensive understanding of the current solutions on the market and the perspective of the end-users of these solutions to create a better decision environment when choosing the path forward.

1.4.4 Thesis location in Apply

In figure 1.2 we see a rough organizational structure that explains where this thesis is located within the company. The other business units and the rest of the executive management (VPs) also have departments with various disciplines, but these are not included in the figure. While the thesis was initiated by DOS, its technical aspects have close relations to Asset Integration & Reliability.

This thesis was initially suggested by Digital Operations Solutions, as a part of their mapping of digital solutions for maintenance systems. However, the field of maintenance software must include a technical aspect as well, therefore, Asset Integrity & Reliability have also played an active role in the definition and conduction of the thesis. The personnel involved from Apply have mainly been located in these two departments.

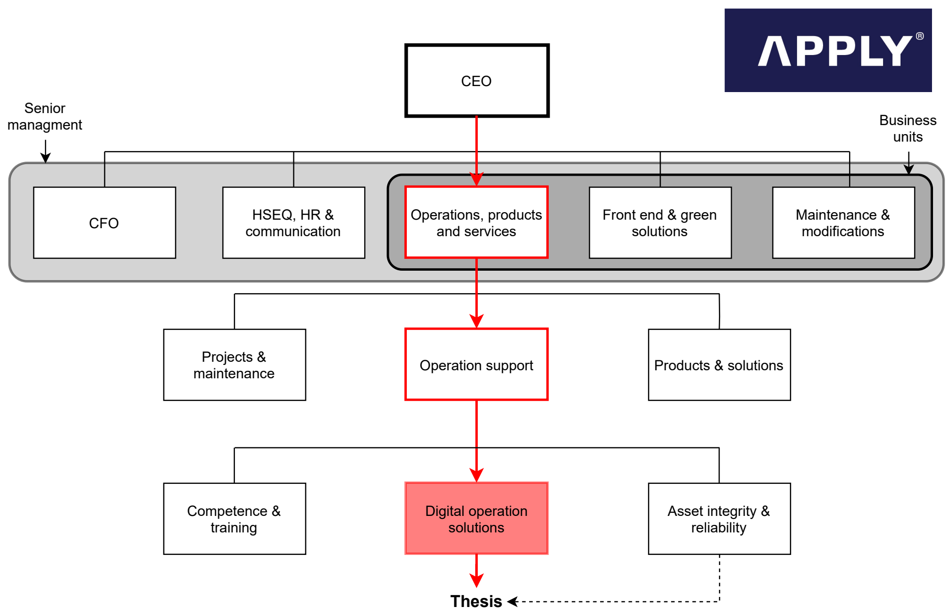


Figure 1.2: Location of thesis in Apply's organizational structure. (Created bu author).

Chapter 2

Methodology

This chapter will present and explain the specific tools and methods used through the entire thesis from the construction of the framework of the project to how certain parts of the analysis are conducted. First, a section on the methodology of the entire qualitative analysis in the thesis, including the scientific reasoning and handling of the qualitative data used. Specifically, how certain data is processed in frequency analysis using methods of coding. Further, how the literature study is conducted to make up a basis for the thesis. Next, a section on how interviews have been used to collect central parts of the data basis. This section also includes the reasoning to how and why the specific interviewees were chosen. Second, to last is how workshops have been used to process and analyze data. Finally, a description of how the business model canvas has been used to compile and present collected data.

2.1 Qualitative analysis

There are many ways to conduct and design a qualitative research. The best design suited depends on the objective and the circumstances of the research. Research with the objective to develop a new theory will benefit from a different research design than one that aims at exploring the individual experiences of a specific case. For this, a combination of several qualitative research designs will be applied to best address the overall objective from section 1.3. The designs included are descriptive design, case studies, and grounded theory.

Descriptive, or interpretive, research design considers how a set of participants view a particular situation. For the interview setting in this thesis, the participants are the interviewees from operator companies and government agency, while the phenomenon to be investigated is the market for PdM software solutions for these companies. Next, case studies are qualitative research design that analyses a particular setting. The analysis considers the views of all stakeholders. Here, the setting is described in the overall objective, and the stakeholders involved are naturally operator companies and their end-users, suppliers, government agency and Apply as an engineering company. Finally, grounded theory research aims to develop a theory based on comprehensive data collection on a particular setting (Billups, 2021). The purpose of the theory is to facilitate further research based on the findings. For this thesis, the primary aim is to analyze the market for PdM-software solutions to create a better decision environment for Apply particularly. By this, the 'theory' developed are the conclusions on the research objective. In addition to creating an improved decision environment for Apply, the analyses conducted and conclusions reached can contribute to the general understanding of the entire industrial setting, and therefore benefit all stakeholders.

When complex systems are to be explored and potentially changed, there is a comprehensive amount of data that needs to be given due consideration. A maintenance system for an offshore installation, with hundreds of thousands of components, people, and software, is without a doubt a textbook example of a complex system. When then also including new forms for technology that are currently poorly understood by the general worker, while also experiencing issues related to skepticism and unwillingness, the complexity just keeps rising exponentially. Corresponding to increased complexity, the challenge, and need, to fully comprehend the system expands. To understand concepts, experiences, and perceptions, one cannot solely rely on numerical data. It will simply not be sufficient. Alongside this objective data, one might also benefit from including other forms of data that describe perceptions, views, comprehensive arguing and reasoning, etc. This is called subjective data. To properly collect this subjective data, various methods can be applied, in general by qualitative methodology. Qualitative methods are valuable to gain insights that can lead to new ideas and solutions for problems. These methods are often superior to quantitative methods by providing in-depth information that is very valuable when exploring challenges with high complexity. Even though qualitative data is more frequently found in social sciences, it can be very useful to derive solutions from seemingly technical challenges as well. Often the challenges are both social and technical.

2.1.1 Inductive reasoning

As explained in the previous paragraph, much of the data collected in this type of research is subjective. This differs from objective data which is more straightforward to interpret. Subjective data needs to be processed more, considering both the message of the data, alongside the circumstances of them. Choosing a suitable method will provide a realistic reflection of the data while also leading to consistency in the interpretations. There are several methods to processing subjective data, this thesis will mainly use inductive reasoning.

Inductive reasoning is a research method where a set of specific information on a portion of a bigger selection is used to develop generalized theories for the entire selection. This research method is very helpful when investigating complex and vast subjects. This is due to the impracticality of collecting all the relevant information from all of the relevant parties (Billups, 2021). According to Silverman (2020), the purpose of induction as an analytical research tool is to detect and unveil relations between attributes and characteristics of the circumstances studied.

The Norwegian petroleum industry constitutes a significant actor in the Norwegian business environment as well as in the international energy sector, involving a great number of companies and personnel. It would therefore be extremely beneficial to utilize the methods of induction for the analysis in this thesis.

Specifically, induction, as a research method, has been applied in the analyses of interviews with end-users, i.e. relevant personnel from a selection of operator companies, interview with relevant personnel from a government agency, and in the construction of business model canvases for suppliers of software solutions for predictive maintenance.

2.1.2 Coding

Coding is a helpful tool in qualitative research and is commonly the first method of processing the collected raw data. There is a strong linkage between coding and grounded theory, much due to that coding is partially defined by the creators of grounded theory (Bell et al., 2019) (Billups, 2021). In short, coding is a process of labeling and organizing raw data into categories to identify themes and the linkage between them. Then, the codes are studied to achieve the aim of the research. When this is said, it is important to also understand and consider the circumstances of the keywords and phrases that are organized into codes. This is an essential part of qualitative research. Therefore, it is crucial to emphasize the significance of include the context of each statement (Johannessen et al., 2020).

In this thesis, coding has been done by extracting keywords and phrases from interviews and sorting them into labeled categories for the themes they are addressing or describing. This was done after the interviewees had approved the summary of the meeting record developed by the researcher immediately after each individual interview. After the results were sorted and the codes were defined, they were explored closer in the frequency analysis.

2.2 Literature review

As a basis for the theoretical aspect of the thesis, a literature study has been conducted. The literature review is essential to identifying where the study field is currently and whether there are areas of little or no sufficient focus. This mapping of the current literature will create an aim and a motivation for the selected research objective of the thesis. This literature review explored the various aspects of the thesis' objective, from business models and market trends to regulatory requirements and technical elements of the corresponding technologies. The literature review has also contributed to identifying areas of interest but with a lack of existing focus. By conducting a proper literature study, the thesis can gather the perspectives from several empirical findings and utilize this to address specific research questions more precisely than previous studies have (Snyder, 2019).

For this thesis, the research questions, presented in section 1.3 , are defined in such a way that they extensively address the overlying objective. Subsequently, the manner of conducting the literature review has been devoted to extensively assign due consideration to these research questions. Given that the data collection conducted as a part of the thesis concern first and foremost research question 1 and 2 regarding end-user perspective on PdM and business models of PdM-supplier, the literature review is primarily aimed at the remaining two research questions regarding the current market situation and how findings can be exploited. Thus, a major part of the literature review was devoted to investigating the literature on the digital solutions for maintenance in the Norwegian petroleum industry.

2.3 Interviews

As a major part of the data basis for this thesis, a series of interviews are conducted. The methodologies used from the structuring of the interviews, to the quality assurance of them, are described in the following paragraphs.

2.3.1 Developing questionnaire

As a part of the structuring of the thesis, a plan was developed on how to best address the overall objective. Interviews were decided would be a suitable method of attaining valuable information regarding this. In order for the interviews to answer the research questions, an appropriate questionnaire was developed. This questionnaire was determined to be quite open, so that the interviewees were free to elaborate and explain as they saw relevant. In addition to the questions, the interviewees were asked to describe their work experience and official role in their company to ensure their relevance. Further, one question was added at the end of the questionnaire regarding if the interviewee would like to add anything. This was done to reach the saturation point of the interviews.

2.3.2 How interviewees were chosen

When defining the scope of this thesis an 'end-user had to be defined. This end-user was thought to be representing a certain role in an operator company that had a suitable balance of influence and authority in terms of maintenance. This led to the definition of 'end-users being a person who holds a managerial role within the field of operations and maintenance. This role has been termed 'asset manager' in the research questions, although the precise title varies from company to company due to their different organizational structure. Different companies are organized variously, thus the job description of the 'asset managers' in the qualitative research were expected to differ as well. To find the people matching the description of the end-user in this thesis, Apply's network was utilized. By asking several people in various companies, appropriate and willing participants were contacted and informed of the project. Some of these were also invited for an initial meeting where the thesis topic was discussed without a strict framework. This was done to better understand the perspective of the participants and their initial thoughts on the subject. This both confirmed that the participants harmonized with the preferred perspective in terms of role and position in the organization and provided indications of how the line of thought and where the priorities of the interviewees would be. These initial conversations helped form the subsequent interviews so that they addressed the reoccurring topics as well as providing a better understanding of the maintenance systems and their corresponding hierarchy as a whole.

2.3.3 Conducting of interviews

The semi-structured interviews started with the interviewer introducing the research, its circumstances and objective. The interviewees were assured that they would remain anonymous and could withdraw their contribution at any time. Next, any questions the interviewee might have were answered by the interviewer. Further, the interviewee(-s) introduced themselves in terms of their experience, education, role and other relevant information to the thesis. Subsequently, the interviewee worked their way through the questionnaire with little boundaries or controlling from the interviewer. This was to let the interviewees speak freely and come with their own reasoning and linkage between aspects. The interviewer supplemented with questions for elaboration and to make sure all questions were addressed. Finally the interviewees could add anything they felt were relevant, or further expand of previous questions. The interviews lasted from 40 to 60 minutes approximately.

2.3.4 Quality assurance

Following the interviews, the meeting records were transformed into a summary of the meeting. The answers provided by the interviewees often addressed more than one question. Therefore, their answers were sorted to their corresponding questions accompanied with the circumstance of the reasoning. Finally, the processed meeting record was sent to the interviewee for clarifications and approval before being used as data-basis.

2.4 Workshops

In addition to interviews with operator companies and a government agency, several workshops internally with personnel at Apply were conducted. These were both in the form of regular guidance and supervision in context to the actual thesis and to solve and discuss findings from data collection and literature review. The Apply personnel involved in these workshops have experience in both engineering, economy, and business and administration, and were at the time involved in either Asset Integrity & Reliability or Digital Operation Solutions at Apply.

Throughout the entire period of the project, there were regular meetings between students and internal supervisors. For the most part, these took place every week, with the rare exception. Varying from meeting to meeting, depending on the topic of discussion, Apply had between one and three people in these sessions. The setup was unstructured, and there was no fixed agenda besides discussing the challenges and findings from the previous week.

In addition to these weekly sessions, a couple of more structured workshops were conducted. In these workshops, the student and four Apply employees participated. The objective of these workshops was to reverse engineer a generalized business model canvas for suppliers of solutions for the predictive maintenance software. As a part of the thesis, a series of these workshops were conducted. In addition to them, subsequent quality assurance via e-mail and unstructured meetings were conducted.

One methodology used in the workshops to attain the generalized BMC was reverse-engineering

Reverse-engineering

As a central part of the data processing in the workshop, a generalized business model canvas for PdM suppliers is developed through the method of reverse engineering. Reverse engineering is a process where a finished product of system of some sort is investigated through being picked apart to be analyzed and understood (Thayer, 2017). In this thesis, the products being analyzed are PdM suppliers. Through information found online and through knowledge held by personnel at Apply, these supplier companies are picked apart in terms of their functions to deduct their business models in the form of a generalized BMC.

Particularly, the reverse engineering process was based on the business model canvas. During the workshops, each block of the BMC was addressed individually. Here, the existing knowledge of the participants, combined with open source information on the PdM suppliers and that attained through unstructured meetings with suppliers, were analyzed and applied appropriately.

2.5 Unstructured meetings

Another method used to attain relevant information has been though unstructured meetings. Some of these are planned and controlled to suit the purpose of this specific research and its objective. However, information has also been attained beyond these methods as well. In addition to the semi-structured meetings, literature reviews and workshops, a series of unstructured meetings have also contributed with valuable data. These meetings were initially a tool for the researcher better to comprehend the field characteristics and workings. Despite this, the information accumulated in these meetings have proved most valuable to the research.

Specifically, the unstructured meetings have been both internally in Apply, and between Apply and one PdM supplier. All parties will remain anonymous. During the meetings, participants were made aware of the thesis and its objective, and reassured their anonymity if anything from these meetings were to be included in the thesis.

Given that the meetings with PdM suppliers were unstructured and unplanned from the thesis' perspective, no meeting records have been written. The information used in the analysis from these meetings will thereby be the general attitude and reasoning of the participants. Further, some quotes underlining these attitudes and reasoning are also included. However, there being no meeting record, these may vary slightly in exact wording. Yet, their message and meaning remain accurate. Since these meetings are unstructured and not controlled to directly address the research questions of the thesis, induction have been applied to the information attained and will contribute in the analysis.

2.6 Business Model Canvas

The business model canvas, explained in chapter 3.4.1, was decided to be applied as a central tool in this thesis. There are several reasons for this. First, the business model canvas is a widely known tool for presenting a company's business model. By using such a commonly known, and acknowledged, tool, the findings and subsequent observations and conclusions from the thesis become more intuitive and more easily comprehended by the reader. Next, the business model canvas is a very simple tool to interpret. The tool comprises the most essential aspects of the greater business model into one page. From this, those studying the canvas can get a pretty good understanding of the main aspects of a company from just one page. Third, the building of the previous point, the fact that it is a fixed and well-defined framework for business models, becomes more easily developed. The clarity of the nine blocks it consists of makes the reverse engineering process simpler. Finally, the clarity explained above, also facilitates a transparent and uncomplicated comparison between business models, which is a central part of this thesis' analysis (Alexander et al., 2015).

As mentioned briefly, the business model canvas have been used to describe the business models of PdM suppliers. Specifically, through open source and existing knowledge on PdM supplier, the business models canvas' were developed through reverse engineering during a series of workshops. One generalized business model canvas, reflecting the current situation of PdM suppliers, have been developed. In addition, an ideal version of the same suppliers, reflecting the desires of end-users have been develop. These are subsequently compared.

Chapter 3

Theoretical Background

This thesis combines information from numerous sources. To understand how different aspects of a maintenance system function together, theory on the different subsections of these systems is needed. This chapter will therefore explore and explain the theoretical basis of the tools, methods, mechanisms, and principles used through the analysis of this thesis.

This chapter will explore the theories and available information on the field of study. First, maintenance and the most important maintenance strategies are explained. Predictive maintenance will be more thoroughly investigated, including some of its most central aspects and technologies. Further, technical and business innovation is defined and explained. Next, the current market situation in the Norwegian industry is described. Finally, business models, their importance, and the business model canvas specifically, are presented.

3.1 Maintenance

Maintenance is a necessary evil. Companies do not want to spend lots of resources on keeping their equipment in expected shape, but if they choose not to spend enough on this they will lose even more money on the consequences. To properly understand how machines and equipment are maintained and kept reliable some understanding regarding different techniques and principles must be understood. Also, to distinguish the peculiarity and advantages of predictive maintenance, elaboration of various other typical maintenance strategies comes in handy.

There are several different definitions of exactly what maintenance is. This thesis will exercise the definition of Heizer et al. (2019) in *Operations Management*, which states that maintenance is the collective term for all activities involved in maintaining the capability of a system. (Tomlingson, 1993).

The Norwegian Petroleum Directorate has calculated that the costs related to maintenance (excluding well maintenance) will, by 2025, exceed 24 billion NOK, making up for over a third of all operational costs. When comparing historically what the costs have been, we see that from 2008 till 2020 the total maintenance cost has increased by just short of one billion NOK while the overall production has been reduced by 6.3 %. There are many reasons for this naturally, more complexity in systems, higher productivity, and thereby more wear and tear on equipment. Still, the maintenance cost has remained more or less stationary for 12 years, only increasing 1% from 2008 to 2020, and expected to increase by another percent by 2025 to 38% *Investeringer og driftskostnader - Norskpetroleum* (n.d.). This show the major cost of maintenance and its stagnation, which raises the need for improvement in this sector.

3.1.1 Maintenance strategies

There are many different ways to approach maintenance. Which approach is the best for some particular equipment or machine depends on the circumstances. Type of equipment, moving parts, age, environment, usage, criticality, and history are just a few of the factors to take into consideration when deciding maintenance strategy.

In the world of maintenance lies plenty of different strategies. Each has some variation to it that separates it from the others. However, with a bird's eye view of the strategic landscape, some collective categories become prominent. A couple of the most common ones, and most relevant to this thesis are explained in the sections below.

Corrective Maintenance

Corrective is one of the most basic and uncomplicated maintenance categories. Corrective maintenance falls under the broader collective term reactive maintenance. Corrective maintenance is the most common reactive maintenance method. As its name suggests, corrective maintenance is a maintenance strategy where equipment is run to failure before maintenance is conduction. These maintenance activities are repairs or replacements of the broken parts, thus correcting the failure after it has occurred. Corrective maintenance is also often called reactive maintenance or breakdown maintenance, both also suggesting the essence of this maintenance category.

Similar to other maintenance categories, the actual practice of corrective maintenance varies to some extent. In some cases, the equipment is run until failure before any maintenance work is conducted. In other cases, the need for maintenance is often identified during other scheduled maintenance. E.g., during scheduled maintenance, a technician discovers failures on adjacent parts and equipment and carries out adequate work to repair the failures before their inevitable failures, following the just-in-time principles. (Wireman, 2008)

Due to its beneficial characteristics, corrective maintenance is widely used by companies operating in almost all industries. These benefits include the simplicity of it, the fact that it extends the utilized lifespan of equipment, lowering of the short term costs related, and the lack of comprehensive planning required. However, corrective maintenance also have some drawbacks. Common disadvantages with corrective maintenance are the long-term costs, poor predictability in failure, and the potential damage the failures of parts can cause to the surrounding system. Considering the pros and cons of corrective maintenance, this solution might be the best when dealing with parts and equipment with low criticality (GeeksforGeeks, 2020).

Figure 3.1, illustrates the sequence of failures and maintenance corresponding to this maintenance strategy. From the size of the maintenance symbol, the illustration shows that the work required in CM often is more comprehensive than in PM.

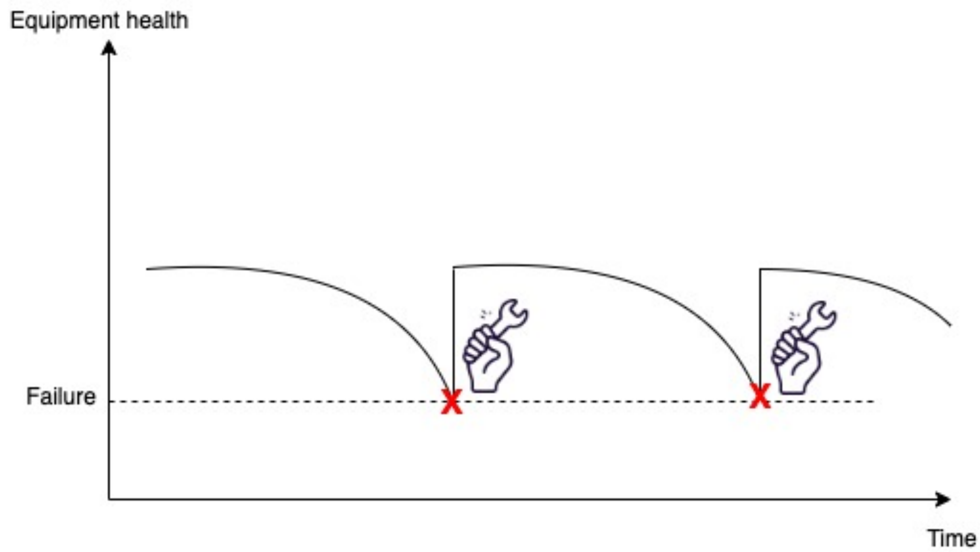


Figure 3.1: Illustration of how and when corrective maintenance is applied. (Created by author).

Preventive Maintenance

Preventive maintenance is arguably the most common maintenance strategy used in the last decades. As the name suggests, preventive maintenance is based on the principles of performing maintenance when the equipment is still functioning properly to prevent failures from occurring. This differs from other strategies which follow a run-to-failure mindset. There are many reasons why preventive maintenance is still so common today despite there being other more advanced and refined methods available. Preventive maintenance is characterized by simplicity and predictability. If for instance, a machine tends to break down every 8-9 months on 80 % of the cases, a reasonable interval to perform predictive maintenance could be 6 months. In this way, the likelihood of failure is quite low at the same time as costs and workload are easily foreseeable. The actual determining of time intervals between maintenance activities are usually calculated based on statistical models and historical data, depending on the criticality of the equipment. Hudachek and Dodd reported in their 1985 ASME article "Progress and Payout of a Machinery Surveillance and Diagnostic Program" that preventive maintenance would reduce costs by 30 % compared with corrective maintenance (Hudachek & Dodd, 1992). This is a significant reduction, especially considering that maintenance costs make up a large portion of the overall operational costs related to industrial companies. Many things have happened to industrial systems and their maintenance requirements since 1985, yet preventive maintenance remains the most common strategy. (Ben-Daya et al., 2016)

In figure 3.4, a typical situation of preventive maintenance is illustrated. Maintenance is being conducted following a strict and predetermined fixed interval. This interval has a safety margin based on a threshold located appropriately in advance of failure in terms of experience. This leads to little unexpected failures, but it also leads to a lot of remaining life that goes to waste.

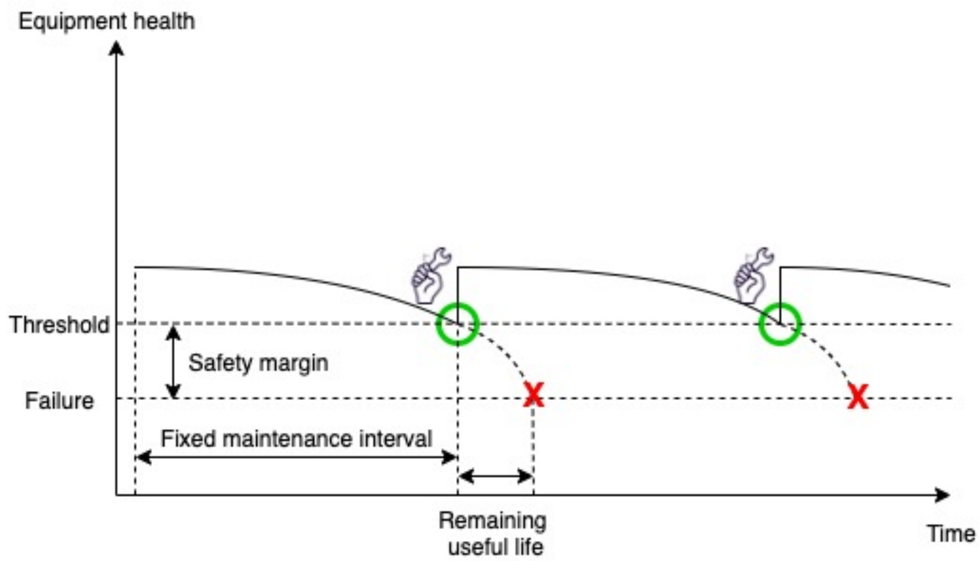


Figure 3.2: Illustration of how and when preventive maintenance activities are applied compared to their potential fully utilized lifetime. (Created by author).

Condition-Based Maintenance

Condition-Based Maintenance is a more advanced maintenance strategy than those explained previously. Condition-based maintenance, or CBM, uses real-time data collected from sensors mounted on equipment to measure some key parameters such as temperature and vibration. This data informs the technicians on the current health status of the equipment. On an offshore installation, there are far too much equipment for the technicians to keep an eye on, so there are software systems that reads the sensory data and set off an alarm when the parameters exceeds a static and predetermined threshold. The methods used to set these thresholds vary but they are commonly based on experience with the equipment, i.e. human-made rules. CBM is a very safe and reliable maintenance strategy. A common understanding is that the setting of the thresholds often are done conservatively, leading to excessive maintenance. Often this is not that big an issue, since the machines being monitored are of high criticality. (neurospace, 2019)

There being so many machines and equipment with varying characteristics, there are specialized systems to process the data flow. These are subsequently collected into an umbrella program, which is the actual program that the technicians will rely on. This collective umbrella program is further connected to the CMMS which organize and schedule maintenance activities when required. This is illustrated in figure 3.3.

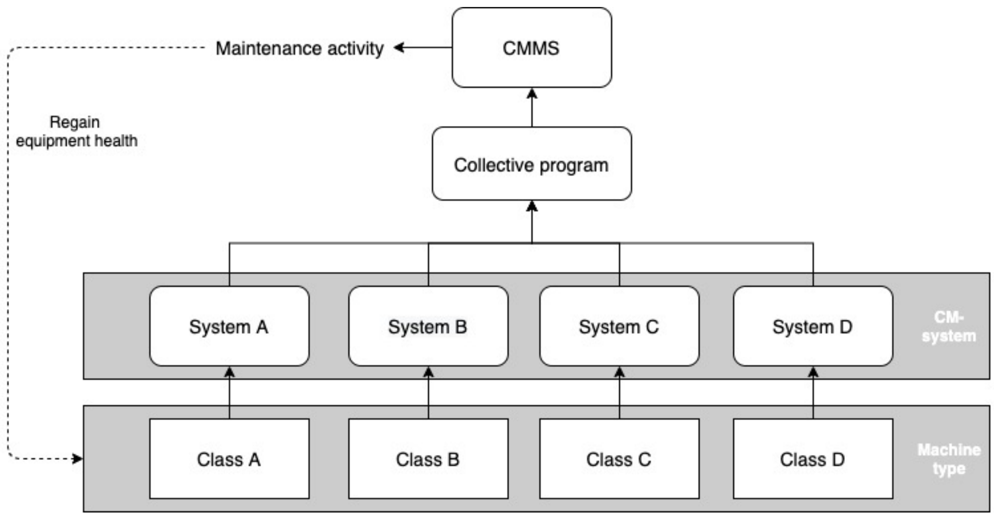


Figure 3.3: Example of typical structure for maintenance systems. (Created by author).

Predictive Maintenance

There are several, slightly differing, definitions of predictive maintenance. When looking up the definition of 'predictive' in Merriam Webster Collegiate Dictionary, we get that predictive means "to declare or indicate in advance. Especially: foretell based on observation, experience, or scientific reason" (Merriam-Webster, n.d.-b). Combining this definition to the one for maintenance described above, predictive maintenance is the field of foreseeing the activities needed to maintain the capability of the system. Building on this, predictive maintenance is a more complex and advanced form of maintenance than those explained previously. One major difference from other maintenance strategies is that PdM is heavily data-dependent. It involves a technique where data from condition monitoring sensors are analyzed to detect anomalies before they develop into failures or defects. In other words, predictive maintenance detects failures so that they can be acted upon before developing into failures. The biggest benefit of predictive maintenance is that it not only foretells failures, it also estimates the expected time before they occur. This capability provides the enormous advantage of being able to utilize equipment at a much higher level while also reducing the corresponding uncertainty (Mobley, 2002).

There are several different approaches to predictive maintenance. In order to properly recognize failure modes of equipment accurately, different approaches can be applied. According to the PSA report (Ellingsen et al., 2019), ISO standard 13381-1 /4/ defines three main categories of approaches:

1. **Knowledge-based** - Using the knowledge, expertise and experience of domain experts to interpret the deterioration of equipment.

2. **Physics-based** - Using known and appropriate formals to detect anomalies and detect failure modes early.

3. **Data-driven** - Data driven models applies statistical models, neural networks (through machine learning), and trends in data to analyze the current-, and estimate the future health status of the equipment.

In practise, it is challenging to clearly differ between these. Often, a combination of them is applied to utilize the benefits of each.

Predictive maintenance is in many aspects a further development of condition-based maintenance. In condition-based maintenance, sensors monitor equipment either constantly or in intervals. When a sensor measures a parameter that is outside some predetermined threshold it triggers an alarm in the form of a work order for instance. The thresholds are often set in such a way that a failure is developing but in an early phase so that the maintenance required is at a minimum. The difference between CBM and PdM is that PdM also applies analyses on the condition monitoring data to predict these failures sometimes before they reach the thresholds. These predictive capabilities can be achieved in several ways, for instance through applying statistical models to the data or by applying some form of artificial intelligence that estimates the expected time to failure. (Upkeep, n.d.) (Levitt, 2011)

Figure 3.4, illustrates a simplified scenario of predictive maintenance. CM is constantly being done, collecting information on the status of all parameters on the equipment. The PdM software detects developments of deterioration when they begin to occur. Simultaneously, it estimates when failure is likely to happen, and calculates, with a safety margin, when the most optimal time for maintenance will be. Figure 3.5, illustrates where analytics and historical data is included into the simplified maintenance system.

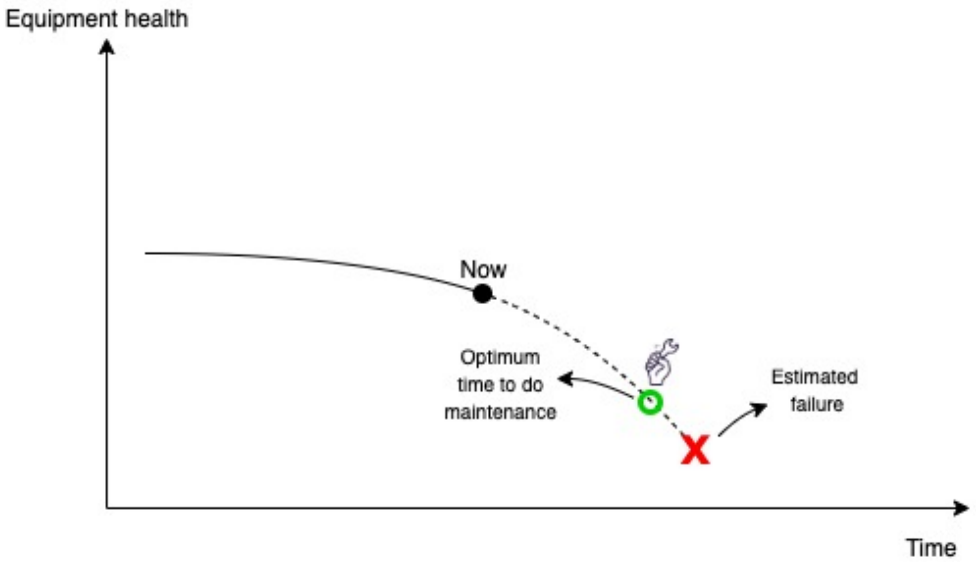


Figure 3.4: Illustration of a typical predictive maintenance scenario where a prognosis is developed and the optimum time for maintenance is scheduled based on estimated time to failure. (Created by author).

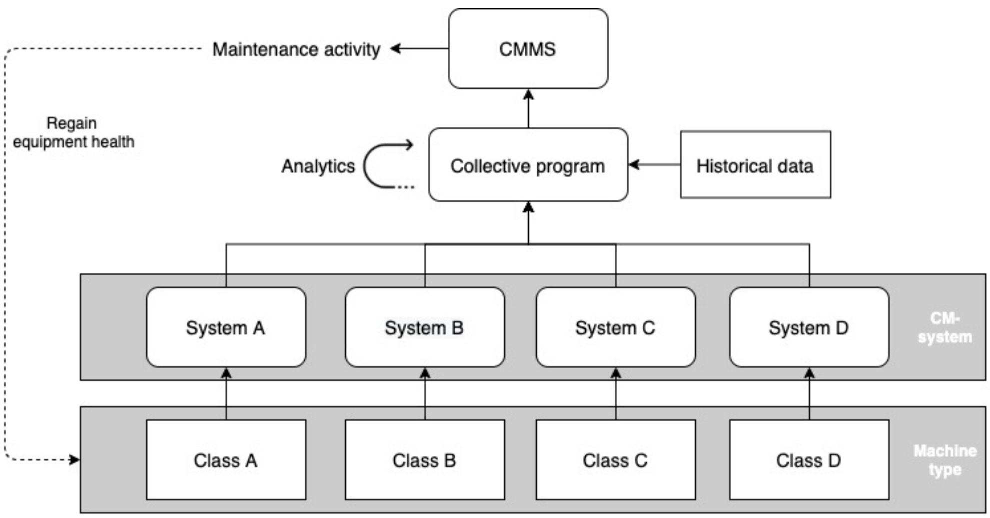


Figure 3.5: Example of a typical maintenance structure with analytics capabilities. (Created by author).

3.1.2 Corresponding technologies and technological trends

Predictive maintenance is a part of a much larger set of innovations emerging in the current times. Some of the most relevant technologies, innovation, and practices to PdM is briefly explained in the sections below. To comprehend the complexity and innovative aspects of PdM, it is crucial to have some basic knowledge of the technologies that make it possible.

Machine Learning for Predictive Maintenance

When data is collected by the sensory equipment and forwarded though the IoT or IIoT capabilities to the analytics software, the algorithms of the software process it and turns raw data into understandable information on health. This analysis often rely on machine learning. Machine learning is an application of AI. Machine learning uses data to constantly improve its algorithms through the data its being fed, and can therefore develop automatically without humans interacting. Machine learning is often categorized by the level of supervision it has, from unsupervised algorithms to reinforced algorithms. (Expert.ai, 2020)

For machine learning in PdM, there are usually a few factors that are taken into consideration by the software when developing the algorithm. These are failure and maintenance history, operating conditions and some static parameters. The failure history concern all operational condition data, both from failures and from when the equipment is healthy. The maintenance history is a comprehensive overview of types and extent of repairs and replacements and so on. The operating conditions explain the current condition of the equipment. The static parameters are just the technical information of the equipment. (Chuprina, 2020)

Industry 4.0

The fourth industrial revolution is the ongoing digitization of traditional industrial processes and practices. As the name suggests, it is the fourth in the line of significant developments in industrial practices across the world. The first industrial revolution introduced the steam engine and mechanization of production, the second brought mass production through the production lines and electricity, and the third introduced connectivity and strong computing power to automate processes. The fourth, or Industry 4.0, or just I4, brings a set of technologies and capabilities such as cyber-physical systems, Cloud computing, digital-twin, big-data, and many more. The central part of I4 is to connect systems and utilize them more optimized. The development from the first to the fourth industrial revolution is illustrated in figure 3.6. (Ustundag & Cevikcan, 2018) (Gilchrist, 2016)

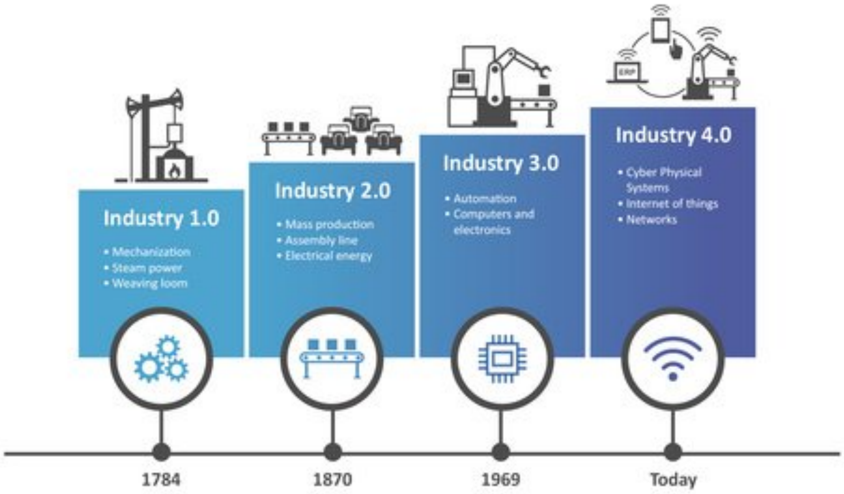


Figure 3.6: Evolution from the first industrial revolution to the fourth, with some key technologies (*Industry 4.0 – Carpani Machine*, n.d.).

Industrial Internet of Things

Another essential technology for data analytics and subsequently PdM to function is the constant collection of real-time data. On an offshore installation, there are hundreds of thousands of parameters to gather, way more than technicians can handle. Through the Internet of things and industrial internet of things (IoT and IIoT), these readings are monitored automatically. One example of IoT and IIoT is when the equipment is connected to the maintenance system and accompanying analytics tools through their sensors. This provides the ability to have comprehensive real-time information on the health status of all equipment included in the system. (Lee et al., 2017)

Figure 3.7: Illustraion of the Industrial internet of Things (McDermott, 2021).

3.2 Technical and business innovation

According to Merriam-Webster Collegiate Dictionary, 'Innovation' is defined as "1. A new idea, method or device, 2. The introduction of something new" (Merriam-Webster, n.d.-a). Combining this with technology leads to a crucial aspect for industrial companies especially. Namely that innovation is key for the success in these highly technological companies. The technological innovation we are talking about here is the ability to utilize knowledge to overcome obstacles and achieve improvements at a technical level. Without this technological innovation, these companies would quickly lose ground in a highly competitive market, and eventually grow obsolete and run out of business. It is this risk of losing the competitive edge that forces companies to invest heavily in developing new solutions to retain their position in the market.

Innovative technology is not necessarily a success right off the bat. Many important factors need to be assigned due consideration for any technology to fulfill its potential and become functional for the end-users. One essential aspect of technology innovation, which too often, unfortunately, is poorly recognized, is the one of market pull versus technology pull. These two represent the challenge of either creating a new solution as a result of the actual demand for it (market pull) or merely due to its cutting-edge technology (technology push). The latter one can lead to good solutions, but no users, while the first one is initiated by demand and will more easily become successful. (Pateli & Giaglis, 2005) (Larsen, 1993)

Business innovation is a slightly different aspect of innovation to the technological. Business innovation focuses on improving internal processes across the entire organization to create an optimized structure for all activities. Like technology innovation, business innovation can come in various forms. One of these is through business model innovation, where the entire business model is revised and made better for the circumstances, e.g. the current and future industrial environment and the strategic objectives of the company. (Cassidy, 2018) (Sorescu, 2017) (*What is business innovation and why is it important?*, 2019)

During a webinar organized by the PSA, the Norwegian Petroleum Directorate, expressed the importance of innovation in the Norwegian petroleum industry (Hald, 2020). During the webinar, the Norwegian Petroleum Directorate emphasized this importance by its influence on the Norwegian community at large. Further, they expressed that the government wishes that the operators utilize new and innovative technology even more than currently, and that it subsequently will lead to value creation. Also, the competence required to utilize these technologies was also addressed as an area of importance for the companies. Finally, the influence of regulations were also pointed at as an apparatus for technology innovation.

3.3 Predictive Maintenance in the Norwegian Industry

The Norwegian petroleum industry has sustained a substantial development since its beginning some 60 years ago. Operations are now far more productive and production is safer, there have been improvements across all functions. As a part of a mapping analysis of the digitization in the Norwegian petroleum sector, Petroleum Safety Authority (PSA) has organized a report investigating the impact on their main areas of interest (Ellingsen et al., 2019). This section will be primarily based on some parts of this report.

During the last 10-20 years, extensive digitization of the Norwegian oil and gas business has taken place. The operators have been taking measures to improve their entire value chain. Software solutions have been introduced to optimize operations and safety, with good results. The industry has had an ongoing effort in investing in better data warehouse solutions with corresponding architecture. Simultaneously, there has been a trend in the industry of improving the interaction between disciplines previously separated, and between onshore and offshore activities. Overall better data management processes have facilitated a transition in terms of maintenance strategy towards real-time condition monitoring and subsequently predictive maintenance. Yet, it is still more of an exception than a regularity that these capabilities are fully utilized on the Norwegian Continental Shelf. The conventional methods of calendar-based maintenance remain the industry standard. This is partly due to some central challenges with a full transition to PdM.

According to the PSA report, there is currently not enough data available for effective data-driven models for predictive maintenance in the Norwegian industry. It is up to the individual operator company and their own cost-benefit analyses if the necessary sensory equipment should be acquired.

Further, the PSA report identifies some areas of interest in terms of further studies. Two of these are how their control inspections will be affected by the data-centered trends in the industry, and how the competence demand will develop in the future. Thus, these are two central areas of importance that require extensive revision and development.

3.4 Business Models

According to Kopp And Brock (Carol M. Kopp & Thomas Brock, n.d.), a business model is a high-level plan for profitably operating a business in a specific marketplace. In other words, the business model of a company is the holistic framework that described the company's role in the market. Basically, it is a representation of the functions a company must have to create a product or service and make money from it from its resources. Today, all professional companies have at least one business model of some sort. The business model captures the key elements of the company's plan in terms of market, customers, values, costs, and revenue.

Today, there are just as many types of business models as there are types of companies. Each focusing on a particular aspect of the business. Even though there are many ways of looking at a business model and defining exactly what it is, the business model canvas is one common understanding.

3.4.1 Business Model Canvas

A business model can come in many different shapes depending on the type of company, type of activities, or just the preferences of management, however, some business model 'templates' are more popular and convenient for most uses than others. The business model canvas is one common example of such a strategic management template for visualizing and developing these business models.

In 2004, Alexander Osterwalder developed the business model ontology, which in 2005 was further developed by Osterwalder himself together with colleague Yves Pigneur to the business model canvas. The bisness mode canvas can be seen in figure 3.8. The principle of the business model canvas is to compromise the most critical components of a company's business strategic plan onto one piece of paper. The model itself consists of 9 building blocks, each representing a critical activity or segment of the strategic plan. These nine 'building blocks', as they are often called, are value propositions, customer segments, customer relationships, sales channels, key partners, key activities, key resources, cost structure, and revenue stream.

After its publication in 2005, the business model canvas has gained a lot of attention for its ability to provide a high-level overview of the company without too much hassle. Today, the business model canvas is being applied in all kinds of companies as well as being included in many management

There are several reasons for this strategic management template gaining so much recognition. First and foremost, the business model canvas is extremely easy to apply for most companies. To map a company onto the canvas is a quite straightforward task for anyone familiar with the company. Second, the business model canvas is easy to comprehend. The fact that the template manages to present everything on one single page makes it effortless to understand it quickly, which obviously is a big advantage when strategic plans often can become too complex to easily comprehend. Third, since the business model canvas has gotten so common, there are numerous online information and tools to make it even easier to use which is helpful for small businesses with less expertise in the field concerning strategy. Fourth, this type of business model provides companies with the perspective of focusing primarily on the customers. By leading with proper value propositions that reflect the needs and expectations of the customers is quite obviously a smart one, however too often companies focus more on the products rather than the problems they are aiming to solve. This is a great advantage of the business model canvas. Last, as mentioned above, this business model provides an intuitive high-level overview, something that facilitates management to get a gist of the entire value chain as a whole.

Even though there are many benefits to the business model canvas as a template for strategic planning, there are also some drawbacks and limitations that need to be investigated and given due consideration. The biggest limitations of the template have to do with its simplicity. As explained above, this feature is also a beneficial one, but with simplicity comes compromises on what to include and what to exclude. One such feature is not included in the relationships between these 9 building blocks. This leads to a segmented characteristic that limits the information possible to extract from the business model. Another drawback to the simplicity of the template is that it does not include strategic growth or development. From this argument, the business model canvas is a static representation of the strategic plan. Another point of criticism towards to business model canvas is the lack of attention towards sustainability and corporate social responsibility. This is something more and more companies include in their strategy and is therefore, a strong limitation to the business model canvas.

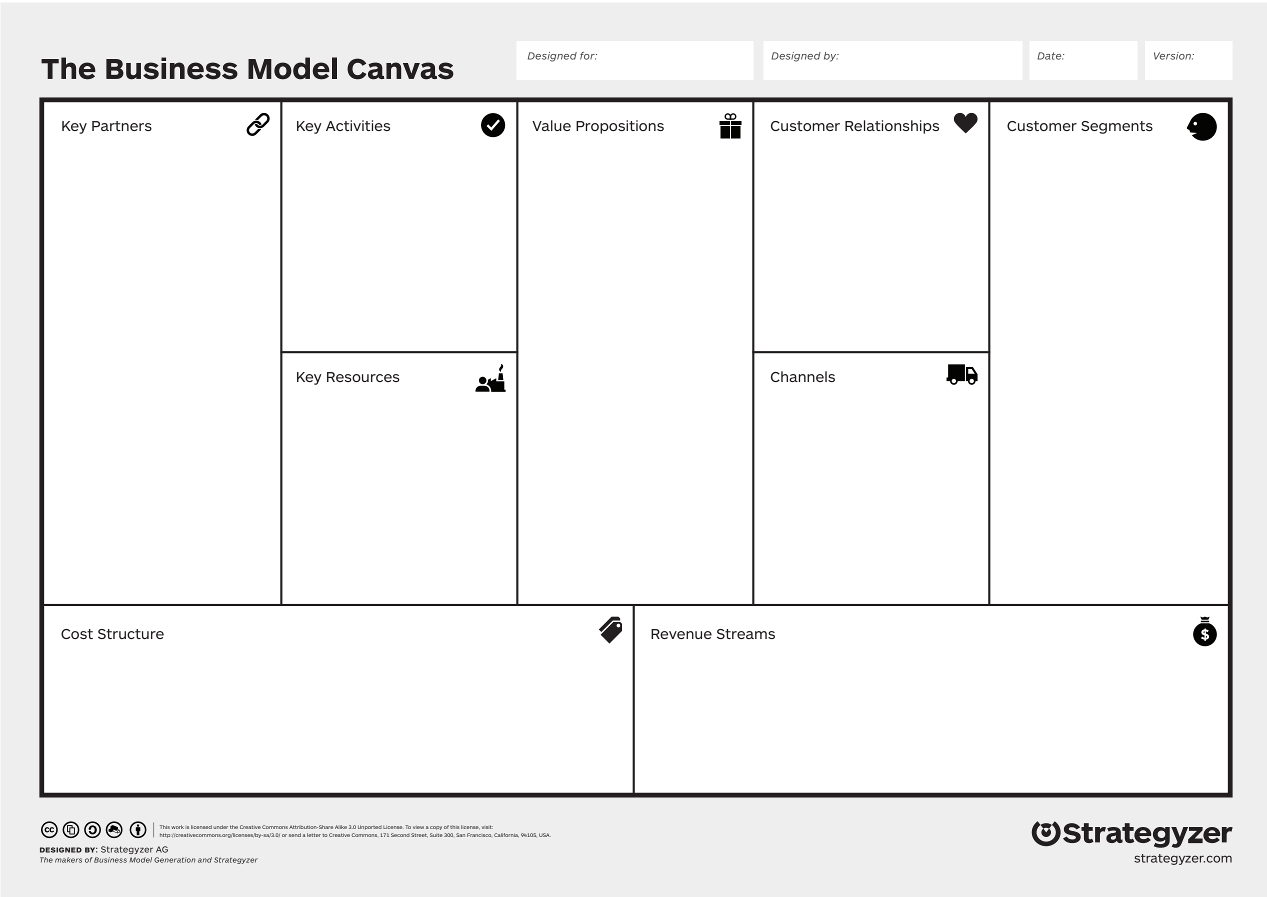


Figure 3.8: The Business Model Canvas by Osterwalder and Pigneur. (Strategyzer, n.d.)

Chapter 4

Results and Analysis

This chapter accumulates the results attained through the usage of methods explained in chapter 2. Subsequently, these findings are processed and analyzed to answer the objective of the thesis and its accompanying research questions.

4.1 Data collection

For this thesis, various methods have been used to collect relevant data. Chapter 2, Methodology, explores and explains these data-collection methods in depth. In the following sections and subsections, the actual data obtained from these methods are presented, starting with the interviews with operator companies and a government agency, followed by results from workshops with relevant personnel from Apply.

4.1.1 Interviews

As a part of this thesis, a total of seven semi-structured interviews were conducted. Six of these were with various relevant personnel from operator companies and one with a government agency. The number of interviewees per interview varied from one to four. In total, there were 11 interviewees, all with experience between six and over 20 years. From the research questions of the thesis, the target perspective was 'asset managers'. The participants from the operator companies were mainly people holding roles as mid-level managers in their companies. Their expertise was primarily operations and management, and hence matched the desired audience for this thesis.

The results from the interviews with the operator companies are summarized in the following paragraphs.

Interviews with end-users

The following paragraphs are summaries of how the participants answered the questionnaire. During the actual interviews, the participants were allowed to explain and elaborate freely across the questionnaire, thus addressing several questions in the same reasoning process. When the individual interviews were finished, a summarized report with their response was sent to them for validation. In these summaries, the answers were organized so that the explanations were sorted under the specific question they address. Thus, the exact wording in the summaries differs some from the actual interviews. All reports were approved, some with minor adjustments. This was done to better explain the arguments while also retaining the validity of the answers. Naturally, when there was a clear linkage in the reasoning between several questions, they were seen together. In the paragraphs below, the summary of all the interviews is sorted into the corresponding questions. By this, the summary in the paragraphs below, except for the quotes, is therefore not in its original wording. Despite this, it remains a direct reflection of the interviewees' responses.

Question 1: What maintenance strategies are currently being used – and why?

The operator companies seem to be quite coordinated when it comes to how maintenance is currently being done. All companies are currently using the conventional methods of corrective and preventive maintenance for the most part. This is due to it being well known, providing good enough results, and being predictable. In addition to these conventional methods, most companies also have some degree of condition-based maintenance on equipment. To what extent CBM is used, varies strongly from company to company and also from asset to asset. While some companies only include their most critical equipment in the extended condition-based maintenance program, others try to include as much as possible, instrumenting new assets heavily to prepare for an inevitable transition towards more automation.

Question 2: What are your, and your company's attitude towards predictive maintenance?

The general response is positive and optimistic. All the companies and interviewees express a positive attitude towards PdM. Many of the participants believe that PdM will prove significantly valuable for oil and gas companies in the coming years. Additionally, all the operator companies explained that there have been conducted some sort of initiative particularly addressed at exploring the potential opportunities of PdM for their company. Some of the companies even have such activities ongoing at the time of the interview. The nature of how these projects were conducted was quite mixed. In general, the smaller companies

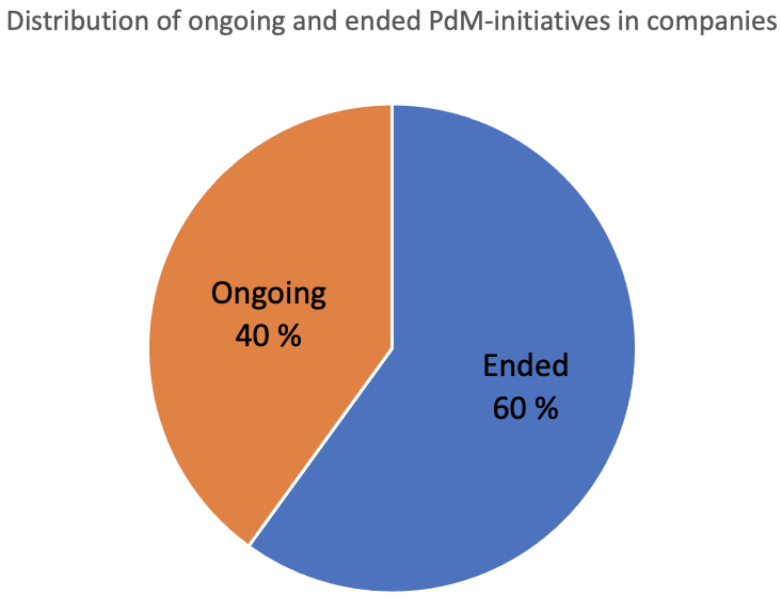


Figure 4.1: Distribution of companies with ended- versus ongoing PdM-initiatives. (Created by author).

had shorter initiatives aimed at mapping potential solutions and their requirements. Some projects solely explored which parameters could be monitored and utilized to detect faults in various equipment to unveil potential areas to introduce predictive maintenance. Other projects consisted of providing external service companies with historical data for certain equipment to see how their data could be utilized better and exactly how early faults and failures in equipment would have been detected. The larger companies that participated in the interviews had the scale and aim of their PdM initiatives in common. Specifically, they had more comprehensive projects that were where, and still are, intended to result in a functioning solution for predictive maintenance. For one particular case, this was obtained and is currently being operationalized to some degree. For the majority, the projects were ended without any planned continued efforts regarding PdM. Figure 4.1 illustrates this.

Question 3: What are the preferred characteristics of any maintenance software?

For this particular question, all interviewees mentioned several things. Some characteristics were repeated by several. One key theme that recurred was the importance of reliability. These systems must prove that they can be trusted through reliable results. One participant said "*Systems needs credibility and precision at a certain level for users to see the full value of them*". Next, its trait of being easily modified to different circumstances was commonly understood to be essential for successful software. This was explained to be due to the broad variety and distinctness of machinery and assets in general. There is no such thing as a "one fit for all" solution in this type of industry where the divergence between seemingly similar systems is so distinct. Thus, adaptability for software solutions is highly valued when integrating them into the organization. Also, the software's capability to be easily modified and made changes to are mentioned to be important, since this is something that has caused lots of frustration among the participants. Seemingly small changes often take weeks to finalize due to the sheer size and complexity of the system. Further, the scalability of the software also plays a role in adaptability and is mentioned by several interviewees. An implementation of a PdM solution needs to be executed in a step-by-step manner. Therefore, a gradually increasing number of machines and equipment will be included in the solution. This naturally demands a highly scalable system. Besides the adaptability, another characteristic was communicated repeatedly by the participants, namely the user experience. The user experience will always be of high priority when software solutions are to be considered. The reasoning behind the strong focus on user experience by the participants is broad, just like the specific features a software needs to provide such a characteristic. According to the participants, a good user experience can be achieved through a well-functioning user interface, transparent processes, and reliability with an easily provable effect, preferably with applicable industrial references. These last points about provable effect will lead to high credibility to the system and security to its users.

Question 4: What are the expected and desired effects of implementing functioning PdM-software solutions for maintenance?

When it comes to expected and desired outcomes and the overall effect of software solutions for maintenance, the interviewees are more or less in agreement. In general, the response was that the overall desired impact seen from an executive manager's perspective will be to reduce the overall cost of operations, including maintenance. However, when explaining the desired impacts of PdM software from their own perspective, the end-users presented a different set of thoughts. The interviewees agreed that the overall improved situation awareness a well-functioning software system provides would lead to optimization of maintenance as a whole, which in turn will lead to better utilization of equipment by lengthening their lifetime while simultaneously becoming aware of errors in an earlier phase of their escalation. Even without predictive analytics, a better situation awareness will in turn result in the right maintenance at the right time. One interviewee emphasized "*at the end of the day, it all comes down to green and yellow lights*". In other words, an organized user interface that presents the current health status of the equipment intuitively. Obviously, if such a system had PdM capabilities in addition, the basis for which these lights are decided would become more accurate and informative. Further, some of the interviewees point out that some of the effects of a well-functioning PdM-system if often overlooked when exploring its impact and whether it is a smart investment or not. The effects they think about are those related to increased production safety. The improvement to the production safety will benefit the health and safety of the personnel that will be less exposed to big machinery and also have a much better understanding of what they are up against before executing maintenance activities. At the same time, the comprehensive situation awareness will provide maintenance planners, independent of being man or machine-driven, a far better basis to develop optimized maintenance plans in terms of database and decision environment. Several interviewees explained their frustration that these beneficial effects seldom are given the due consideration they deserve when examining and considering software solutions. One interviewee expressed that "*It is in the combination between technologies and our people we will find solutions for the future*". While another pointed out that "*What the desired effect or impact is of these software solutions will differ greatly from who is asked. Executive management will have fundamentally other priorities than maintenance managers and engineers, even though they all wish for a more optimized maintenance system.* ".

Question 5: What are the biggest challenges for PdM, both in general and for your company in particular?

Despite the companies and interviewees all having a positive attitude towards predictive maintenance, they all underline that there are a few challenges to overcome for this technology to meet its potential and be operationalized on a large scale. The challenges that the interviewees elaborate on vary from the strictly technical side, to the organizational side and on to the human aspect. Naturally, with such a complex and innovative technology, complexity in organizations, and the amount of effort needed to integrate this across all levels of a strongly conventional industry, many different challenges arise. It will come as no surprise to anyone that there is no simple solution for such an advanced challenge, and neither will it be solved overnight by a hand's turn. The response to this question covered a vast spectrum of challenges associated. Through the interviews, the participants talked about the challenges related to the enormous cost of such investments, the lack of knowledge to properly develop, integrate and run these systems, the lack of data to train algorithms adequately, and the associated lack of willingness to share data, black-box problems related to not understanding the systems properly and thus not trusting its predictions, the amount of maintenance work that cannot be assigned to PdM-systems due to their obligation to carry out function testing, there is currently no industry standard on how these predictive maintenance systems should be designed, and finally, the fact that the general culture in the industry often is reluctant and unenthusiastic to disruptive change even though it might bring value. One of the interviewees used an example to describe the situation we are in now with regards to conventional maintenance versus predictive maintenance; "*the last horse was far better than the first car but now we see how this has changed with time*". In other words, current "conventional maintenance" might be better than the first-generation predictive maintenance, but it will not last very long, soon predictive maintenance will outperform the traditional methods and the industry will move on.

Question 6: Do you have any other thoughts related to the issue?

With a completely open question to end the interviews, the participants were free to elaborate on anything. Yet, most of them took the chance to further expand on the challenges and further underline that a transition to PdM for the oil and gas business will need to happen in a gradual step-by-step manner. In addition, some other interesting observations were presented. Some interviewees explained that suppliers of maintenance software were leaning towards obtaining more responsibility for production capability and reliance from their customers. E.g., transitioning from purely selling software to help organize and plan maintenance, to actually perform all activities maintenance-related besides the actual execution of the work. This type of business model is often referred to as Maintenance as a Service. Most of the participants mentioning this trend also added the challenges related to this. From a governmental point of view, it does not matter who might be internally responsible for product safety, if anything is to happen it is the operator company who must take the blame and make sure to fix it. Governmental imposed responsibility cannot be delegated to third party companies, but they can be hired by operators to do tasks related. Further, some interviewees pointed out the importance of companies showing their willingness to innovate and improve. It was explained that if there is a technology that is thought to improve a company's processes, it would not look good if the company chose not to investigate it. In practical terms, this translates to companies not willing to explore the possibilities and potential of new technological solutions such as predictive maintenance capabilities. On the Norwegian Continental Shelf operator companies never work alone, they are imposed to share the responsibility of the assigned area with other companies. At the same time, for companies to be assigned these areas, it does not solely come down to the economic strength, the tender rounds also include their ability to operate according to the Norwegian government's intentions. If some of these are not willing to implement potential improvements the relationship with the rest of the industry might sour. In turn, this resistance to exploring potential improvement is likely to not only cost the companies dearly in terms of opportunity cost but will likely also result in a poor starting point when applying for operating contracts.

Interview with government agency

In addition to the interviews with a selection of relevant personnel from operator companies, one interview with a governmental agency was also conducted. The agency has the regulatory responsibility for safety, emergency preparedness, security, and the working environment for the petroleum industry in Norway. There were four interviewees present, all working with HSE and maintenance management and all with several years of experience. These participants were given different questions than the operator companies due to their governmental perspective.

Question 1: What are your agency's attitude towards PdM?
Similar to the response from the operator companies, the participants from the regulatory agency also have a positive attitude towards predictive maintenance as a technology. However, their regulatory responsibilities concern the areas mentioned above, i.e., safety, emergency preparedness, security, and the working environment for the petroleum industry in Norway. This means that their focus is on keeping these areas optimized and well-functioning, and not interfering with the particular technology each company uses to meet their requirements. In other words, the agency does not care all that much about exactly what type of technology the companies use, rather that they can meet the requirements.

When reflecting on how the general maintenance is being done in the oil and gas business today, the participants agree that for the most part the 'conventional' methods are preferred. According to them, all companies in Norway still have preventive and corrective maintenance making up the majority of their maintenance work. In addition to these certain imposed requirements, the government agency has some instructions regarding companies' initiatives to improve and optimize. This forces the industry to constantly move forward and keep its competitive edge, both internally but also externally towards the international market.

Question 2: How can checkups and inspections by your agency be conducted when decisions are being made by algorithms with little accessibility to internal processes?
The interviewees acknowledge the challenges occurring with regards to their supervisions when there is little accessibility to the decision sequence. I.e., it becomes much more difficult to track and trace decision sequences when they do not involve any human interaction. However, the participants do not experience this being a large issue at this time. This is due to that, in general, maintenance still requires extensive human interaction. Nevertheless, the participants expect this to become a rising issue in the time ahead. Yet, this does not mean that the imposed checkups and supervisions will need to be reduced, rather than the technology implemented to analyze condition monitoring data to activate maintenance activities must have features that allow access to the basis on which the decisions are made. Or in other words, the systems must be transparent to map out the decision sequence.

The participants further explain that predictive maintenance is not likely to become a complete and total maintenance solution, rather a supplement for certain equipment. This is due to many things, amongst them the fact that a lot of maintenance is imposed to ensure requirements associated with production safety and other areas governed by the agency. Yet, the participants do believe that the technology will grow and become more common. One striking reason is the fact that many companies today chose to have equipment underwater. Subsea installations require condition monitoring since regular inspections by people would be practically impossible. This trend is believed to help push the development of predictive maintenance.

Question 3: What are your thoughts regarding the HSE aspect of optimized maintenance?
The participants agree that while there is an interesting environmental aspect regarding improved and optimized maintenance, especially in terms of a potential reduction in required man-hours as well as an extension of expected lifetime for equipment, they do not feel that this subject matter falls under their jurisdiction.

4.1.2 Unstructured meetings

In addition to interviews, data were collected through participation and observation of unstructured meetings internally in Apply and between Apply and one supplier company. The meetings internally in Apply were both addressing this thesis and its concerns, and other operations and projects, particularly in the departments of Digital Operations Solutions and Asset, Integrity & Reliability. During the meetings between Apply and a supplier of PdM software, the participants were made aware of the thesis and its objective at the beginning of the meetings.

From a qualitative research perspective, the meetings were unstructured. By not having a structure, the discussion was allowed to drift between subjects and issues. This led to a relaxed and open discussion environment where only the main topic was predefined. Further, the meetings between Apply and PdM suppliers were not initially a part of the thesis. Thus, the structure of these meetings was not defined corresponding to the objective of the thesis. By this, the meetings were strictly focusing on business between the companies, and no official meeting records were written. Thus, data from these meetings, e.g. quotes or similar, are not exact and may differ slightly in wording. Yet, the essence of the data remains accurate. These meetings contributed to gaining valuable information on the attitude and objective of the supplier of PdM-solutions.

During the unstructured meetings with a PdM-supplier, some interesting findings were collected. These are, for the most part, used in the development of the generalized business model canvas for PdM-suppliers. In addition, the findings from these meetings supported the development of the general impression on the general market for PdM-solutions in Norway.

Specifically, the objective of the supplier's initiative with Apply became prominent. Not surprisingly, the interaction aims to create a partnership with Apply as an engineering company to assist with the technical aspect of their services. This will provide them with the existing extensive expertise of an engineering company with a strong position and large network in the Norwegian industry. The company also expressed their desire to reduce their own involvement in the process to solely delivering the software. Activities beyond this would be assigned to either the engineering company, in this case, that would be Apply or other partners. In reality, this was not currently possible, so the PdM-supplier was forced to possess the required capabilities and expertise themselves for now. Still, this remained an optimal scenario.

Further, during one meeting, it was stated that "*there is no need for proof of concept. A pump is a pump regardless of the circumstances*". This statement was made in the context of a discussion concerning the company's lack of industrial references from the Norwegian industry. The statement expressed the insignificance of not having results to show from the Norwegian industry. According to the PdM-supplier, industrial references were not of any importance due to them having well-functioning solutions to show for from other industries in other countries.

4.2 Analysis

The analysis will explore, process, and investigate the data presented previously, aiming at addressing the overall objective and the corresponding research questions defined in chapter 1. First, the results from interviews with end-users of the PdM-suppliers are investigated. Further, the regulatory perspective of the subject is discussed. Later, an ideal and a generalized business model canvas is developed and explained, followed by a comparison of the two. Finally, a section on the general impression and observations with suggestions to the utilization of industrial opportunities is presented.

4.2.1 Interviews with end-users

The data used to answer this research question was obtained through the semi-structured interviews described in section 2.3 and presented in the section 4.1.1.

By applying the method of coding when conducting qualitative research data analysis, one can sort and recognize the most important aspects of the results. The aspects, or themes, are the categories that reoccur and strongly influence the data collected. In this case, the results from the interviews are much easier analyzed when properly coded into some primary themes. To find suitable themes, the use of research questions defined in chapter one as the basis is helpful. From the first research question regarding the objective of the end-users on predictive maintenance solutions, compared with the results from the interviews some central themes appear. For this thesis, the analysis becomes more intuitive when dividing the indexing themes into two main sections, one for the preferred and required features and characteristics of software solutions for predictive maintenance and one for the challenges of these solutions. The separation is beneficial due to the interdependence of the aspects discussed within them. This being a complex field, the aspects are heavily dependent on each other as will be further explored later in the analysis.

Desired features of PdM-solutions

When exploring the results from the interviews by applying methods of coding, in particular from questions 2 and 3 regarding desired features and effects from maintenance software, some keywords and phrases recurred. When discussing and explained these questions, the interviewees tended to iterate back and forth between the desired impacts and characteristics. This is likely due to their interdependence and linkage from their perspectives. Therefore, in table 4.1 below the keywords and phrases used to describe both the desired characteristics of a predictive maintenance system and what the end-users would like to get as an impact by these systems are sorted into suitable codes. Subsequently, by sorting the keywords and phrases into two main categories, corresponding frequency diagrams are developed.

First, a description of the codes and their corresponding categories.

Technical characteristics

When applying the method of coding on the keywords and phrases from the interviews, the first process of filtering is conducted. The codes are chosen based on the impression and circumstances of the statement during the interview. By studying the codes extracted from the interviews, two main categories became prominent, namely characteristics and impacts. These categories were expected to emerge considering the formulation of the questions. Question number 4 addressed what specific features these solutions should have, while question 5 concerned the overall impact of a well-functioning PdM system.

Considering the characteristics category, there are four codes, flexibility, integration, reliability, and ease of use. These are all features that are solvable by technical attributes. Exploring them one by one will provide a more comprehensive understanding of their essence.

Table 4.1: Frequency analysis of keywords and phrases related to desired characteristics and impacts of a PdM-solution sorted into codes

Word /phrase	**Frequency**	**Code**
Reduces maintenance cost	2	Cost reduction
Good user experience	3	Ease of use
Easy to implement	1	Ease of use
Intuitive	1	Ease of use
Integration	4	Easy to integrate
All-inclusive / complete	2	Easy to integrate
Complies to other systems	1	Easy to integrate
Works with other systems	1	Easy to integrate
Scalable	2	Flexible
Easy to modify	1	Flexible
Ability to grow	1	Flexible
Improves safety	2	Health and safety
Reduces workload	2	Operation performance
Increases uptime	2	Operation performance
Lengthens equipment life	1	Operation Performance
Lower emission	1	Regulatory compliance
Transparent	1	Regulatory compliance
Innovative	1	Regulatory compliance
Large data base	3	Reliable
Data management	2	Reliable
Credible	1	Reliable
Precise / accurate	1	Reliable
Reliable	1	Reliable
Has proven effect	1	Reliable

Table 4.2: Sorting codes for desired impacts and characteristics

Table 4.3: Characteristics

Code	**Frequency**
Reliable	9
Easy to integrate	8
Ease of use	5
Flexible	4

Table 4.4: Impacts

Code	**Frequency**
Operation Performance	5
Regulatory compliance	3
Cost reduction	2
Health and safety	2

The first one, flexibility, is mentioned both directly and indirectly in the interviews. By flexibility, the end-user seeks the ability to be modified to suit their specific assets. A major part of the flexibility attribute is the aspect of co-creation. Several interviewees expressed their frustration with solutions that did not easily modify and that is was they that had to adapt, and not the solution. This is an unfortunate consequence of inflexibility in software solutions that are applied to immensely varying systems.

The next characteristic code is integration. The aspect of integration concerns the solution's ability to function alongside all other systems in a company. When looking at the figure **??**, it is clear that even internally in maintenance systems there are often a large number of maintenance programs involved. The same thing goes for other parts of the organization, especially when operating offshore installations. This involves logistics, supply chains, inventory management, moving people from site to site, etc. All these require some sort of software solution, favorably that functions seamlessly together. This integration is, therefore, a large concern for the end-user. Many companies now use comprehensive ERP systems that cluster all these capabilities together into one solution. At the very least, the solution must be integrated so that it functions alongside these ERP systems.

The third code, and the one with the highest frequency, is reliability. The absolute largest concern from the end-user in the interviews was the actual reliability of the solution. This code groups all matters related to provable effect, precision, the size and handling of the database, its credibility among users, etc. Many interviewees explained situations where a PdM solution had been used, however, the analysis was not trusted so that the operators had to check everything themselves as well. If a PdM solution is to be well-functioning, it must be reliable in every aspect. An issue is the hidden layers in the algorithm and analysis processes, which do not let engineers see how predictions are made. This leads to skepticism. For the solution to be reliable, it must have provable results from good industrial references and become more easily understandable and interpretive analyses, it will become a far better tool for the end-user.

The fourth, and last, characteristic is the ease of use. Both the suppliers and the end-users recognize the importance of user experience. During one interview a participant stated "it is in the combination between technologies and our people we find solutions for the future". This strongly reflects the general attitude. For the solutions to function properly, they must provide the end-users with value through good user experiences. According to the interviewees, a good user experience is usually attained through a variety of features. Situation awareness, intuitive user interface, and seamless integration with other parts of the organization are three things that are mentioned repeatedly in the interviews.

Operational impacts
The operational impacts expressed by the end-users are the overlying effects of PdM. There are four operation impact codes. These are operation performance, regulatory compliance, cost reduction, and health and safety.

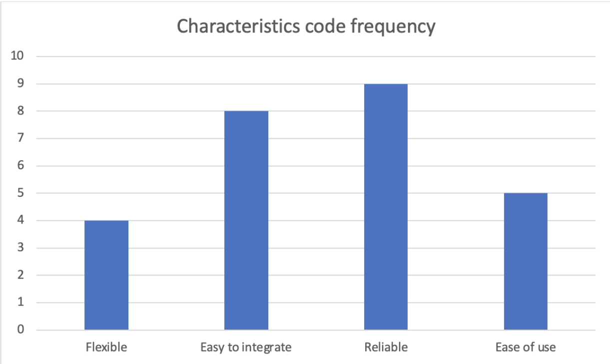
The first code on operational performance reflects the typical value propositions from suppliers on their websites. The attributes that correspond to this code are reducing unplanned shutdowns and downtime for production, and fewer maintenance activities, and hence more optimized maintenance activities. These are the overlying impacts in terms of maintenance systems, related to technical aspects but without a clear explanation on how they will be attained.

The second is regulatory compliance. When operating on the Norwegian continental shelf, there are some particular circumstances that all companies must give due consideration to. These aspects are both the regulatory requirements related to performance, emissions, controls, etc., and other factors in the industrial environment like how an innovative maintenance system can objectively impact applications for licenses positively. The way the Norwegian industry is constructed, partnerships, and accompanying reputation is of great importance.

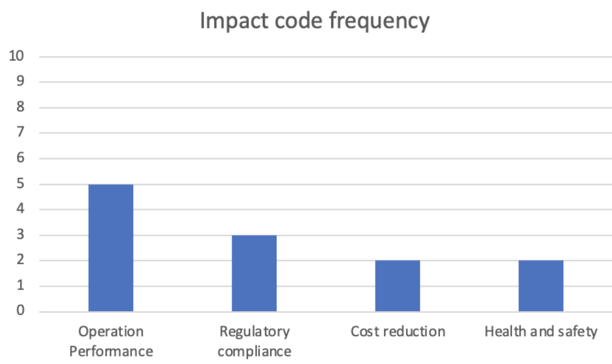
Operational impact code number three is cost reduction. Naturally, as an overlying objective to the entire operation, cost reduction is of great interest. The way this is achieved is through some of the other codes, less work, longer lifetime on equipment, and reduced downtime. It is interesting to see that even though cost reduction, at the end of the day, is the target of maintenance optimization, it the lowest frequency of all.

Finally is the code for health and safety. Interestingly enough, one of the recurring themes concerning the impacts of PdM software solutions is the aspect of health and safety. Like some of the other codes, this is mentioned alongside other keywords and codes throughout the interviews. Not only will reduced workload cut costs and improve performance, but the personnel will also be less exposed to heavy machinery and hence lower risk of accidents.

In figure 4.3 and 4.2 the frequencies of the codes and the code, categories are illustrated in a pie-chart and two bar charts.



(a) Characteristics code frequency



(b) Impact code frequency

Figure 4.2: Frequency bar charts of desired impacts and characteristics of PdM-solutions. (Created by author).

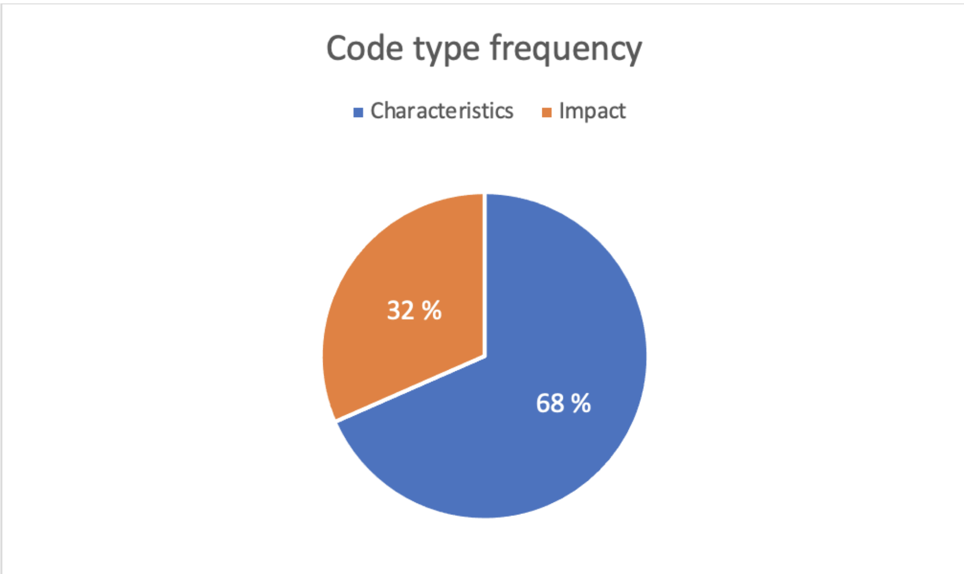


Figure 4.3: Frequency distribution of codes for desired impact and characteristics of PdM-solutions. (Created by author).

Challenges with PdM

Most of the responses regarding challenges were collected from the response on question 5 concerning this exact aspect of the technology. However, throughout all the questions in the interviews, the participants expressed various issues and challenges associated with predictive maintenance and their software solutions. The nature of these challenges diverged to different areas of such solutions. In table 4.5, keywords and phrases concerning the challenges to predictive maintenance and their frequency (number of times mentioned in all interviews combined) are sorted into codes.

Similar to the coding done on desired characteristics and impacts, the codes concerning challenges are also reasonable to sort into groups to better understand and distinguish trends.

Table 4.5: Keywords and phrases related to PdM challenges sorted into suitable codes

Word / phrase	**Frequency**	**Code**
Black box	4	Algorithm
Algorithm development	1	Algorithm
Lack of competence	3	Competence
Lack of technical expertise	3	Competence
Lack of expertise and experience	1	Competence
Lack of knowledge concerning support systems and algorithms	1	Competence
Cost of development	2	Cost
Operational cost	2	Cost
Conservative industry	2	Culture
Poor commitment	2	Culture
Companies are not internally ready	1	Culture
Managerial commitment	1	Culture
Data access	2	Data
Implementation	3	Implementation
Putting it to use	1	Implementation
A lot of equipment cannot have PdM	3	Regulatory
Lack of industry standard	2	Regulatory
Develop a good user interface	3	User experience
Create value for end-user	1	User experience
Human – machine synergy	1	User experience

Table 4.6: Sorting challenge codes into two main categories

Table 4.7: Technical challenges

Code	**Frequency**
Algorithm	5
User experience	5
Implementation	4
Data	2

Table 4.8: Industrial challenges

Code	**Frequency**
Competence	8
Culture	6
Regulatory	5
Cost	4

Regarding the challenges, the codes are separated into two groups, technical and industrial. The technical codes concern challenges related to the actual technology for the individual solutions and issues surrounding this. I.e., challenges that do not take into account the circumstances in which it is operating. This is where the industrial codes come in. These have a broader perspective and look at PdM solutions from an industrial environmental level.

Technical challenges

For the technical, there are 4 codes. The first is implementation, it concerns issues related to actually getting these solutions up and running in organizations. From the interviews, the participants repeatedly elaborated on troublesome situations and sub-optimized solutions due to them not being sufficiently implemented. Some interviewees explained that they have experience failed attempts of introducing new software solutions or other tools due to halfhearted commitment. These statements are also backed by the software providers themselves observed in the unstructured meetings. Here, the suppliers explain several cases where customers complain that they are not seeing value in the solutions they have bought. After investigating this, the suppliers often unveil that the issues that are experienced are due to the solutions not being properly implemented and integrated.

For the second code, user experience, many interviewees expanded on the issues regarding poor user interface. These challenges are often indirect where the end-users are not getting the full value of the tool. Several also explained the importance of good situational awareness in these types of software to obtain a good user experience. As seen in previous paragraphs, situation awareness is strongly sought after and at the same time seen as a challenge to attain.

The challenges related to data are explained to be in terms of too little accessible data to develop a reliable solution. While likely is enough data in the industry, there are troubles and complications surrounding data sharing and data ownership between companies. Some initiatives have been made to create common databases like OREDA (OREDA, n.d.), However, these have not yet succeeded to solve this challenge completely.

The fourth challenge code concerns the algorithms themselves. Like the other codes, this also consists of various sub-issues. The challenges surrounding the algorithm are related to it actually being able to detect faults and failure earlier based on reliable inputs than the current solutions, but mostly not being transparent and thus creating a so-called black box scenario. The issues of black-box scenarios are that both the end-users feel uncomfortable initiating costly and comprehensive maintenance activities without being able to see how data has been analyzed and which data parameters have triggered the alarm. Further, there are issues to regulatory inspections of the process when they cannot be fully mapped.

Industrial challenges

The first industrial challenge is something all participants discussed, namely the issues concerning a lack of competence in most companies. Exactly what type of competence was in mind here varied, however, it is quite apparent that there is not enough expertise on the different aspects of predictive maintenance and its corresponding software solutions. Competence gaps related to algorithm development, technical expertise on the systems it will be supporting, and support systems that must be adapted it will be integrated with are just some of the areas mentioned in the interviews.

The challenges related to cost could be sorted as technical but due to its overlying influence on the industry as a whole, it has been included as an industrial challenge. A large issue with the cost is the extensive opposing views of operators versus suppliers of the solutions. While most operators point out the major challenge of costs related to PdM solutions, the providers of these solutions estimate enormous cost savings for their customers. For one, AVEVA claims 10-digit savings as one of its values (AVEVA, n.d.). The distance between end-users and suppliers here is far too big and is, therefore, a large challenge.

Further, one aspect that is pointed out many times is the culture of the petroleum industry. The participants explain that the issue with the culture comes as a result of poor results, poor commitment, and poor competence. These three affect each other negatively in a loop (see figure 4.4). It is by many participants described as conventional, traditional, restrictive, and skeptical. These all work against the introduction of new and innovative technology. The interviewees subsequently explain that to not lose focus and motivation, the shift towards PdM must be a gradual step by step process. If not, it cannot be successful. This also relates to the cost of introducing it and the job of attaining competence. It must be done over a period of time for it to happen. These three challenges, culture, competence, and cost are strongly connected.

The last challenge code concerns the regulatory difficulties. A great deal of maintenance work is related to function testing critical equipment. Hence, it cannot solely be monitored by a system, it must be regularly tested. This is due to regulatory requirements. Further, the issues described earlier related to black-box scenarios in the algorithms also concern governmental requirements of mapping out decision processes for control inspections.

In figure 4.5 and 4.6, the frequencies of the different challenge codes and their categories are illustrated.

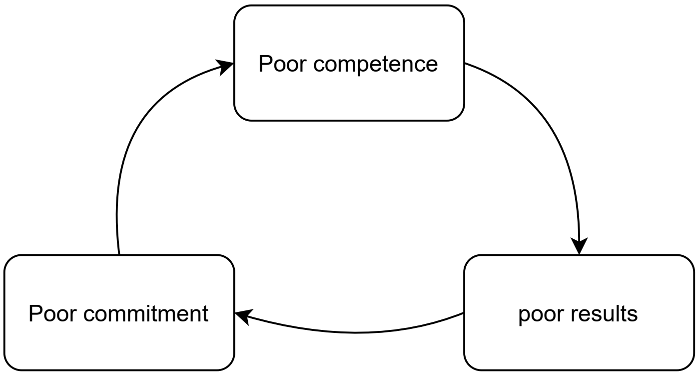
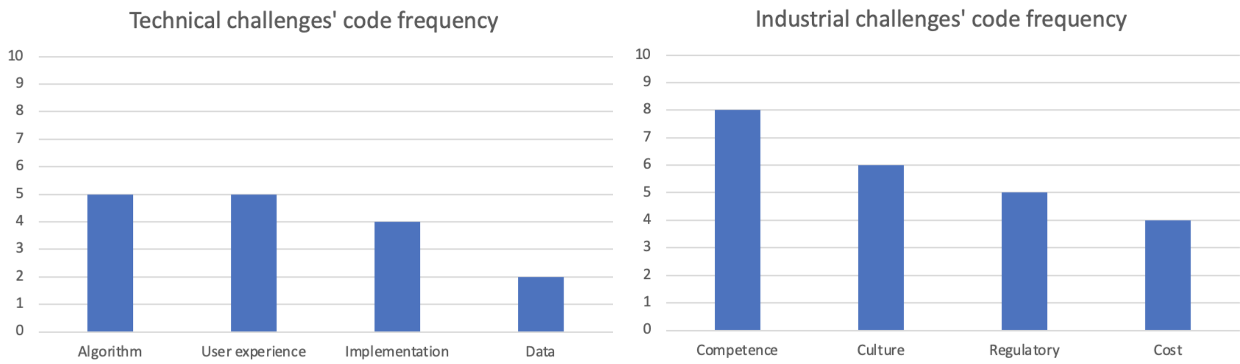


Figure 4.4: Loop of negatives leading to a skeptical culture. (Created by author).



(a) Technical (b) Industrial

Figure 4.5: Frequencies of codes for challenges to PdM sorted into main categories. (Created by author).

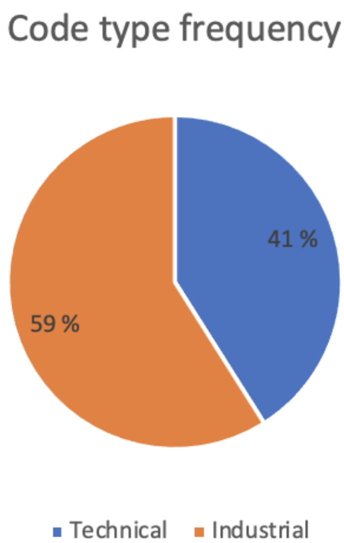


Figure 4.6: Frequency distribution of codes related to PdM-challenges. (Created by author).

Comparing code category frequency

The following paragraphs will investigate the frequencies of the code categories closer, starting with the desired attributes and subsequently the challenges.

Desired attributes

When comparing the frequency of the code categories regarding desired features of the PdM solution, some interesting numbers emerge. In figure 4.3, we see the keywords and phrases related to technical characteristics have double the frequency of those related to impacts. This could indicate that the general focus of the end-users is more aimed at specific technical attributes than at the overlying impacts. Considering this together alongside other statements from end-users regarding that PdM-suppliers promise far greater operational improvements than they manage to achieve in pilot projects, a clear connection unveils. While suppliers proclaim radical benefits and improvements, the end-user chooses to favor specific technical attributes, which in turn will lead to greater impacts across the system. In other words, the suppliers' focus is on comprehensive impacts, while the end-users are more focused on the specific technicalities leading to these.

Challenges

The difference in frequency between the technical and industrial challenge code categories is less than for the two code categories for the desired attributes. Yet, from figure 4.6, there is still a distinct 50 % distance between the two challenge code categories. The technical challenges make up 59 %, while the industrial ones constitute 41 %. Similar to the desired attributes, the technical aspect is clearly the focus of the end-user. The industrial challenges of PdM-solutions are still very much of interest, however, the first concern of the end-users is the specific technicalities.

4.2.2 Regulatory perspective

There is a clear concern from a regulatory perspective on PdM-technology. This is underlined in the interviews with both operators companies and the regulatory agency, as well as in the PSA report and webinar talk by the Norwegian Petroleum Directorate explored in sections 3.3 and 3.2. When elaborating on how maintenance is currently being done, most of the operator companies explained that there is a lot of maintenance work related to functional testing to meet standard requirements. These jobs cannot be assigned to an automatic software system, they must be physically done regularly. The main concern for this matter from the operators was that any maintenance system, with predictive capabilities or not, cannot replace these activities. Several of the participants also stated that the workload related to these requirements made up a majority of their maintenance. This impression strongly complies with the response from the interview with the regulatory agency. They stated that a PdM solution will not be able to become an all-including maintenance system and that companies must realize this. They further explained that while PdM technology is likely to become superior to traditional methods in many aspects, it will remain a supplement for the bigger maintenance system. By this, the reasoning was that predictive maintenance will be aimed at a smaller section of the maintenance systems such as detecting failures in running equipment and estimating expected time to these failures due to the regulatory requirements on much equipment.

Further, the participants representing the regulatory agency underlined the industrial requirements of improvement efforts. The Norwegian petroleum industry has a proud reputation of being highly productive and optimized in all aspects of the operations like carbon dioxide emissions, safety, and production levels. This results in two incentives for operator companies to give PdM-technology due consideration. The high-performance level on the NCS pushes the operators to constantly strive to improve all its processes to attain a competitive edge. Subsequently, there is an overlying governmental request that the Norwegian industry continues this while also strengthening its position. This leads to requirements for all companies operating in Norway to improve as well. In other words, they are governmental requirements on operators having a constant improvement effort on all its processes. If there is a better way of doing something, the companies are obliged to utilize these possibilities. Thus, if predictive maintenance becomes superior to traditional methods of maintenance, the are regulations that push for companies to implement this. Naturally, for such complex systems, it is not always straightforward to conclude which system is best, which will depend on several parameters. Yet, there is a regulatory incentive to explore the possibilities of improving, including on maintenance.

4.2.3 Ideal Business Model Canvas

A lot of information has been collected through the interviews with the end-users. The perspective of the interviewees and their companies have been used to develop an ideal version of the business model for operator companies. This means that this business model is based on both direct and indirect statements and reasoning from the interviews. The purpose of this business model canvas being constructed is to clarify the opinions, needs, and wants of the end-users. Being based on several companies, this model is a generalization of their response, analyses, and explanations.

The business model has been constructed in a series of workshops with relevant personnel at Apply. The actual canvas and thorough explanations for each of the nine blocks in it will be presented below.

Customer segments

The first block to examine is the customer segments. Through the interviews, the participants expressed the importance of their suppliers understanding the industrial environment in which they are operating. This means that the suppliers are taking the regulatory require-

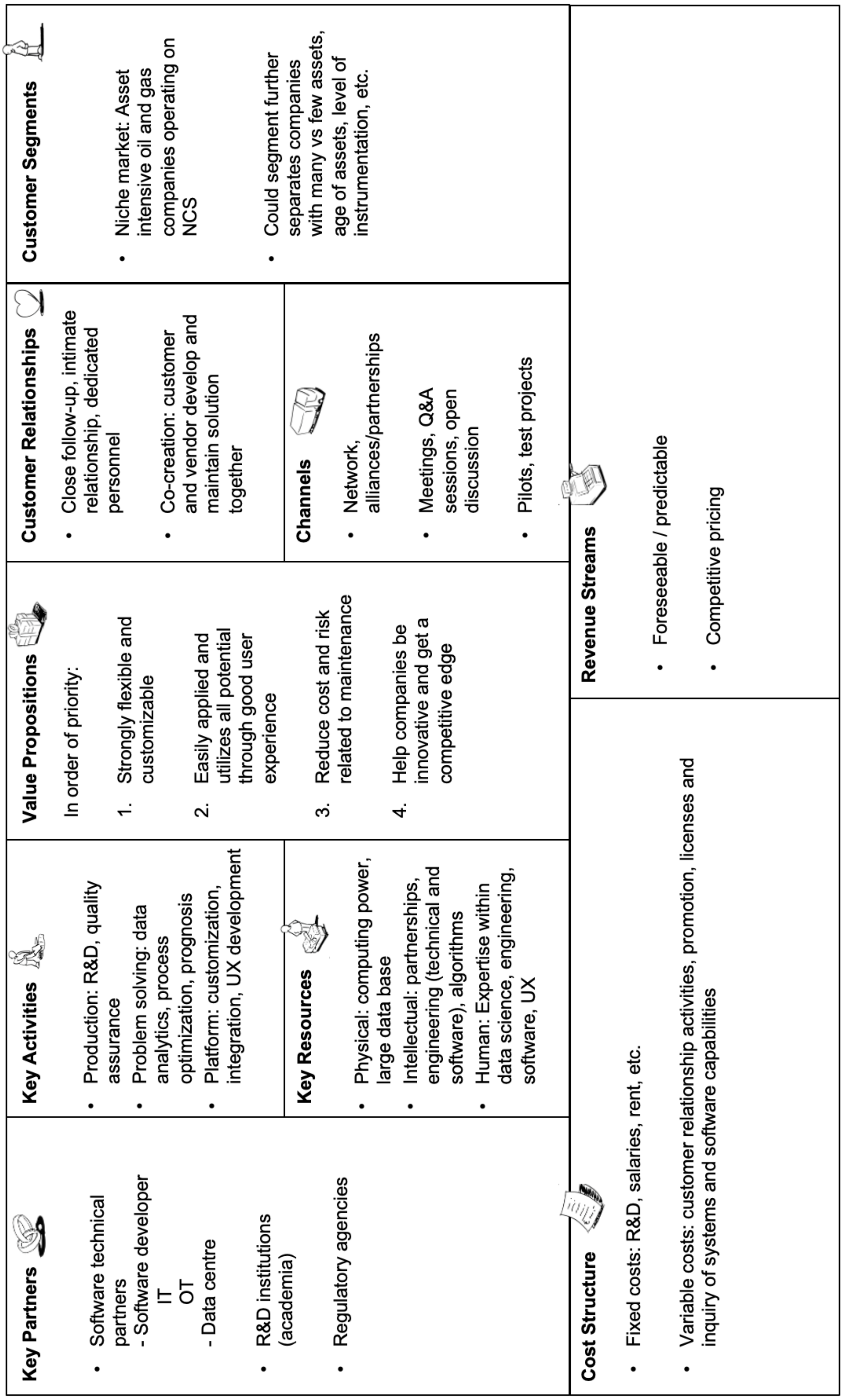


Figure 4.7: Ideal Business Model Canvas. (Created by author).

ments, physical conditions, and other important factors into consideration when developing solutions for them. Hence, the operators favored a supplier that had a niche focus on their particular industry. This means that the solutions are developed for asset-intensive oil and gas companies on the Norwegian continental shelf. Subsequently, some interviewees expressed that an even further specialization for customers/operators with different needs would be beneficial. This means various solutions depending on several parameters such as asset age, level of instrumentation, size of the portfolio, etc.

Value propositions

Next, the value propositions are attained from responses to question regarding the desired impact of these PdM software solutions. The interviewees expressed many desired outcomes and impacts of a well-functioning PdM system, and several explained that they would likely be the same as for any other maintenance system. This clearly indicates that the overall objective for the participants is not to introduce new and innovative technologies, but rather to optimize their processes. From the frequency analysis, the end-users were more focused on the technical characteristics of the solutions than on the overlying operational impacts. In the value proposition block, four key factors have been derived from the interviews. These are to boost operational performance through higher uptime and optimized maintenance while meeting all regulatory requirements.

Sales channels

The third block in the canvas is the sales channels. Here, it is described how the value propositions are delivered to the customer. The participants did not elaborate all that much on this aspect, they were more focused on what happens after the connections with suppliers had been made. Nevertheless, when looking at how the various PdM projects have been conducted, some indications on what is preferred can be extracted. Initiating projects seem to be easier when it involves people who already are acquainted and companies who have a preexisting relationship. In other words, initiating a PdM-project with someone in the customers' industrial network simplifies many things. Further, thorough presentations, discussions, and focus groups with both customers and suppliers of PdM-solutions will answer way more than some generalized information found on the web. This is naturally required when acquiring these solutions. Further, pilot projects as the final step before purchasing a solution. All operator companies from the interviews had run a precursor project of some sort before settling on whether to proceed or not. Then, the three steps mentioned are a method of gradually moving from a generally available solution to ensuring that it will practically provide value for the specific system it will be applied to.

Customer relationships

Block number four is the customer relationship. This being a high cost and high-risk industry, naturally there will be a close relationship between supplier and customer. Further, the interviewees expressed that they would very much like to participate in the development and designing of their particular solution so that they were optimized for their needs and wants.

Revenue streams

Block number 5 concerns the matter of revenue streams. There are not many specific requirements of the operators here. Yet, some mention the trend in revenue streams where suppliers are moving towards a so-called Maintenance as a Service (MaaS). These trends concern models where suppliers sell units of production rather than maintenance service. In other words, the suppliers sell for instance working hours on their equipment. This could be a good solution but in reality, there are some prominent obstacles. One of these is that while an operator could delegate the production, they are not able to resign from production responsibility. One interviewee stated that the cost of a breakdown is way more expensive than what a MaaS maintenance program could make up for in savings. Therefore, these are not as favorable for operators at this time. The primary focus of the operators is a competitive and predictable cost.

Key resources

Until now, the blocks of the canvas have focused on what values to deliver to whom. Now, the left-hand side of the canvas focuses on how to attain the value proposition. Block number 6, the key resources, are what is needed to deliver everything discussed so far. For PdM providers, the end-users would like there to be quite a few of these resources available. The three main categories are the physical resources involving mainly computing power and access to large amounts of data, intellectual resources in terms of expertise on software development and technical engineering, and the third is the human aspect considering the ability to utilize the other resources properly to their specific systems.

Key activities

The key activities are the appliance of methods and tools to attain and deliver the value propositions. The ideal case from the perspective of the operators is also divided into three main categories. The first is regarding production and involves the actual development, improvement efforts, and quality assurance of the solution. Next, the actual problem solving, analysis of data, and prognosis development is naturally a key activity. These will need some input from experts even though AI-based algorithms should be adequate. This is to assure the reliability of the solution. Lastly is the continuous effort of improving and further developing the user experience of the solution.

Key partners

Second to last is the key partners' block. This block contains the external partners which will be executing the activities that are outsourced. Ideally for the operators, as much as possible is done by the supplier themselves. This ensures them that the technical expertise and the software developer are at the same level. It was mentioned several times in the interviews that a conspicuous issue with these parts not working closely leads to the software not meeting the desired focus and subsequently that the solution becomes sub-optimal. Nevertheless, some key partners are important in the eyes of the operators. These are academic partnerships, making sure that the technology is according to the academic standards. This type of technology is rapidly evolving, and it is imperative to keep up to retain a competitive advantage. Further, a connection to regulatory agencies is also of great importance. This allows them to also keep up with regulations which also rapidly develop alongside technological evolution.

Cost structure

Finally, the ninth block is related to the cost structure of the supplier. Exactly how the suppliers form their cost structure is not of the highest importance for their customers. However, through the interviews, there was a common desire from the operators that the PdM-providers strive to attain unambiguous results from their data. This means more research, better algorithms, more computing power, attaining more competence, and being able to offer even more specialized solutions. This will naturally result in some large costs. In other words, the end-users do not desire their PdM suppliers to have large costs. Yet, the ideal business model for these suppliers will lead to some significant costs.

4.2.4 Workshops

The workshops were used to generate a generalized version of the business model canvas for a supplier for software for PdM-solutions. The structure and conduction of the workshops are described in section 2.4. The data used to develop the generalized business model canvas was partly collected through the unstructured meetings presented in section 4.1.2.

Generalized business model canvas for PdM-suppliers

To easily make a visual representation of the PdM-suppliers business models, a generalized business model canvas has been reverse engineered. This canvas is based on open-source data from a selection of companies developing software solutions for predictive maintenance. In addition, workshops with relevant personnel in Apply, and unstructured qualitative data collection by participation and observation of unstructured meetings between Apply and some of these software providers have been used as a foundation.

The companies used to construct the canvas are AVEVA (AVEVA, n.d.), Presenso (Presenso, n.d.), Cognite (Cognite, n.d.) and Karsten Moholt (Moholt, n.d.). These four were

chosen due to their strong position in the Norwegian industry, while also representing a variety of backgrounds and approaches. While AVEVA and Presenso are big international companies, working across many industries, Karsten Moholt has a more niche market focusing on Norwegian companies and rotary equipment. Cognite was founded in 2016 and has grown to become a dominant actor despite its short history. Today Cognite's largest owners come from the Aker-group, which subsequently has a lot of power to control Cognite, while also making up a large portion of their customer base (Proff.no, n.d.). These four make up a good representation of how typical actors in the market do business. In addition, these are four companies that Apply, and their employees are well familiar with and thus companies with a lot of accessible information.
These are four companies that all compete for contracts with operator companies in Norway. Despite them aiming for the same clientele, there are some differences between them. This canvas is a generalization of them and will therefore not reflect any one of them completely. The following paragraphs investigate and explain each block of the generalized BMC, block by block.

Considering the customer segments, there are primarily two common and conspicuous approaches from the companies, namely mass market and niche market. Mass market is typical for the larger companies operating internationally and across several industries. The other is characterized by being narrower, focusing heavily on solutions for rotary equipment for companies operating in Norway. Still, there are some aspects of the customer segments that are alike despite this. Both are aimed at asset-intensive companies, such as petroleum operators.

In the value proposition block, key points from the PdM suppliers are used. There are some prominent differences in what their focus is. The majority prioritize the benefits related to performance improvement such as boosting uptime and reducing unplanned maintenance. These are operational impacts that their solutions are expected to result in. Yet, some choose to promote more detailed beneficial features of their solution like co-creation, user experience, and easy integration. The different approaches seem to be aimed at different hierarchical levels, the first toward executive management, the latter at mid-level management, and hands-on users.

Block number three considers the sales channels used by the supplier companies. Based on Apply's experience with these companies and their websites, we see that several channels are being used. The most important tool for the companies is their networks. Their ability to get in touch with the right people and discuss the solutions with them seems to be the preferred way to go. In addition, webinars, articles, social media, and newsletters are all used to promote the company and find new potential partners and customers. Considering the scale of contracts, when connections are made the next natural step is to set up a series

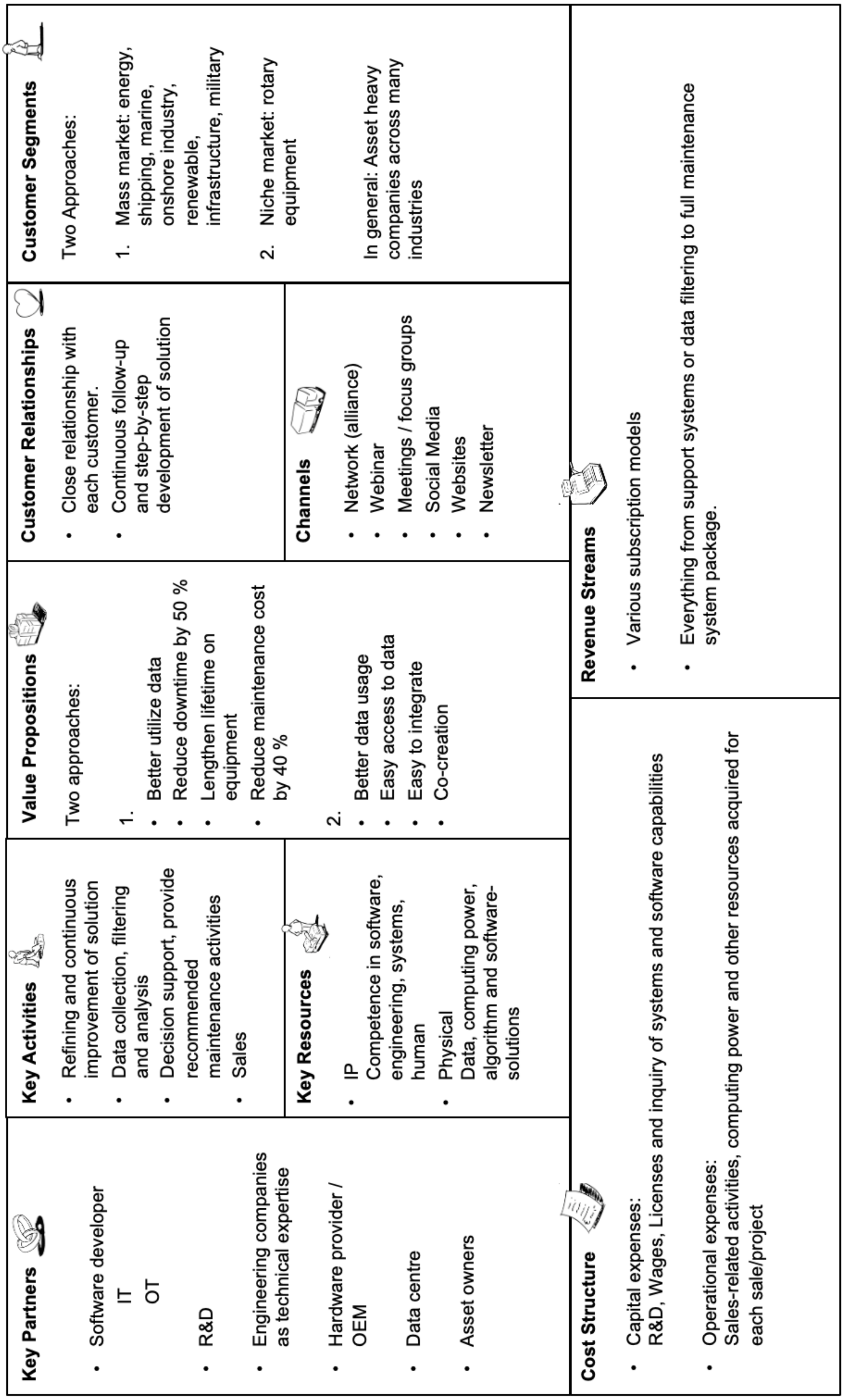


Figure 4.8: Generalized Business Model Canvas based on results from open source data and unstructured observations, constructed by a series of workshops. (Created by author).

of meetings to convince customers that the solution is the right one for them. Some supplier companies also have pilot projects or similar to further convince and ensure their ability.

Next, the customer relationship is considered. Considering the scale of these solutions in terms of monetary cost and potential value, it is quite natural that there are close relationships between the involved parties. For such complex and comprehensive solutions to fully function, there must be close follow-up and designated personnel to resolve any issues that may be encountered. In addition, some companies also enable the customers to modify the solutions so that they better fit their current systems. This is usually done within a predetermined frame. There are some dissimilarities in the service available after implementation. Some suppliers have competence internally to assist, while most prefer partnering up with another company to handle all service-related work.

The fifth block is the revenue stream. By checking out the websites of some PdM solution suppliers, it is easily seen that subscription models are preferred. This impression has been confirmed during unstructured meetings with some of these companies. A subscription model will provide them with a predictable income while also having the opportunity to increase their sales by expanding the subscription package annually. There are still companies using the traditional ‘cash up-front model, however, the general impression from both suppliers and customers is that this is changing.

Block number six deals with the key resources needed to deliver the value proposition. The are many resources needed to deliver PdM capabilities, some more essential than others. First, intellectual property. This is crucial in terms of possessing the right competence within the central fields of the technology. This being within software engineering, technical engineering, and systems integration. Further, the physical resources required to deliver predictive analyses, the companies must have sufficient computing power and a big quantity of relevant data.

Key activities, from block number seven, explain how the key resources are applied to attain the value propositions. Primarily, the activities directly related to these value propositions are things like data collection, analysis, and interpretation leading to prognosis. In addition, there are key activities related to research and development initiatives, continuous improvement on algorithms, and user experience. Another important activity which could be termed as indirect, underlined from the supplier companies themselves during unstructured meetings, are all processes related to sales. This is a necessity and required plenty of both time and effort.

Second to last is the key partnerships block. In this block, the partners which hold the resources that the supplier companies do not have themselves are addressed. What the supplier company has internally and what they need to get from partners depends on several factors such as the size of the supplier company. While some companies wish to deliver most of the services related to solutions themselves, others wish to strictly sell the software and let their partners get the service-related contracts. Some of the suppliers have expressed the desire to sell as little service as possible while others build their entire revenue stream around delivering services. The latter is the more common. For most though, the key partnerships include suppliers of IT and OT solutions, engineering companies with technical expertise, equipment manufacturers, and academic institutions.

In the ninth, and final, block the cost structure is explored. For simplicity's sake, it is divided into OpEx and CapEx. CapEx is wages (assuming the same number of FTE's independent of contracts), research and development, licenses and access to systems, and rent. Further, the entire cost structure is heavily influenced by the OpEx. One independent contract for a supplier company involves sales activities, acquiring external expertise for the specific system, and acquiring the needed additional computing power from data centers.

4.2.5 Comparing the business models

This section will include a comparison of the generalized business model canvas and the ideal case business model canvas. Additionally, gaps, unrealized potential, and harmonies will be unveiled and explained.

Thus, this section addresses research question 3 regarding consensus between the end-users and the suppliers and research question 4 regarding how the findings can be commercialized.

In previous parts of the thesis, two cases of the business model canvas for suppliers of software solutions for PdM have been derived and explained. One of these was based on the results from interviews with relevant personnel in several operator companies to attain the desired case or ideal case. The other was based on how a variety of these suppliers actually function currently, a generalized case. Ideally, these two are agreeing with each other. This ideal case is a situation where all the market is in full harmony and balance. However, this euphoric circumstance is rarely the case. Realistically there are some compromises from both sides. The following paragraphs will explore how far apart these two business models are.

To do this review analytically, the business model canvases will be systematically studied block by block, like they have been explained earlier. Subsequently, a brief conclusion on the major findings will be presented.

Customer segments

From the end-user perspective, the response on the customer segments is quite clear; narrow and specialized on their particular circumstances are absolutely preferred. Further, the interviewees expressed the importance of having clear industrial references from their environment. The suppliers had varying approaches on this matter. Some did specialize in niche markets such as rotary equipment on the NCS, while others included the Norwegian industry as a part of their mass-market approach. During unstructured meetings, one of these suppliers expressed "*there is no need for proof of concept. A pump is a pump regardless of the circumstances*". This contradicts the perspective of the end-users.

Value propositions

Similar to the customer segments, there are two main approaches to value propositions. The majority of suppliers chose to focus on performance aspects, namely how the overall system will be impacted by the PdM solution. Things like reduced downtime, cost savings, and longer lifespan on equipment. One supplier, in contrast, focuses on the technical aspects and characteristics of the solution. How data easily can be accessed and improved use of data. The response from the end-users is in favor of the latter. The response, as seen in the pie chart in figure 4.3, shows that these aspects were mentioned twice as many times as the overall impacts.

Sales Channels

For the most part, the response from interviews with operators and the generalized case is in agreement regarding the sales channels. The preferred tool is, by far, the network of the companies. The network consists of people and other companies with which they are familiar and likely also have or have had cooperation or partnership. There is a lot of people moving from company to company in the Norwegian industry, which leads to the companies being tightly linked through both business and acquaintances. This results in more straightforward processes of initiating and promoting sales. The only minor issue unveiled regarding sales channels is the reluctance to pilot projects from certain suppliers due to their ow value and large time consumption, from their perspective. This is desired from many end-users, partly due to the lack of industrial references.

Customer relationship

In terms of customer relationships, the two business models are quite similar. Both recognize the comprehensiveness of such solutions is chose a close relationship with designated people to provide follow-ups. Further, there is to some degree also agreement in terms of co-creation. The interviewees expressed repeatedly that no systems are alike, thus there is no such thing as a one for all solution. The solutions must be adapted to fit the corresponding system. Most suppliers agree while some allow more flexibility than others. Further, who provide the follow-up differs from end-users to suppliers. While several suppliers wish to get a partner to provide this, the end-users prefer that the technical support and expertise is delivered from the same company providing the software solution.

Revenue stream

For this block, the two parts are in agreement. The suppliers tend to move towards a subscription model. This provides more flexibility and more predictable expenses for the users. However, the MaaS model, which some are exploring, will seemingly be dysfunctional for the operators in terms of risk and responsibility.

Key resources

Even though the formulation in the two business models is somewhat different, they are quite similar in terms of the key resources. Both agree that there are various types of resources required for these PdM solutions in terms of expertise and competence, IP aspects like algorithm and software, and some hardware like computing power and data. When this is said, they do not completely agree on where these resources come from and who should hold them. While end-users desire all resources to be held by the supplier, the suppliers themselves have a varying attitude towards this. Some hold much of it, except for instance computing power, while others allocate this to be delivered by their partners. This is discussed in ´key partners´.

Key activities

The wording used to describe the key activities in the two business models are somewhat different. However, they do concern about some of the same aspects. Both agree on the most essential activities required to deliver a well-functioning solution, namely continuous R&D initiatives, constant co-creation and development of individual solutions, and the actual analytics involved around data and maintenance prognosis. However, while the end-users express that assistance to analyzing and managing the data is a key activity from the supplier, the suppliers themselves focus more on sales. This is naturally an important aspect for them, but from the perspective of the end-users, the resources this requires could be better applied to improving solutions.

Key partners

Some quite prominent differences emerge in the key partners' block. As clearly expressed in the interviews, the end-users wish that the suppliers have most of the expertise themselves rather than involving even more companies into the mix. This will not only make for a more seamless system, but it will also ensure that the technical expertise comes from people who are also strongly competent with the software, and vice versa. The suppliers, on the other hand, tend to allocate much of the expertise to other companies. One must add that this is the case for some of the biggest actors on the market, and not necessarily for every single one. The bigger supplier companies wish to partner up with technical expertise and let them handle technical support. The end-users favor that the key partners are other actors in the industry, such as regulatory agencies, academia, and the existing providers of IT and OT solutions to ensure a smooth integration.

Cost structure

In terms of cost structure, the end-users do not express strong opinions. However, they naturally do have an underlying expectation that the suppliers invest adequately in aspects like R&D and training. The suppliers themselves, have a reasonable attitude on their cost structure. Some capital expenses like wages are basic, in addition, there are investments in software, R&D, and licenses. In terms of the operational expenses, there are marginal costs related to each client in terms of computing power and so on.

Conclusion of Business Model Canvas comparison

As expected, there are many blocks in the business model canvas that look quite similar between the two cases. The highest degree of complies was found in key resources, sales channels, revenue stream, and cost structure. Common for these blocks is that they either have little direct impact on the end solution, like cost structure and revenue stream, or they concern uncontroversial parts of the business model, like resources needed or the sales channels. Further, there are some blocks with less compliance, namely key activities and customer relationships. The issues with these are strongly linked. The largest difference in terms of how the relationships should be is the aspect of co-creation. Some suppliers prefer a standard package with slight modifications in their solutions, while the end-user desires flexibility and complete influence in design. This is reflected in key activities, where several end-users demand more assistance in their operations, also after implementation. Yet, the suppliers prefer to implement the solution and potentially let other companies (partners) be available for assistance. The areas with the most inconsistency are value propositions, key partners, and the customer segments. The largest actors seemingly do not recognize the importance of specialized solutions for particular industries. Some expect to get large contracts without a single reference from the Norwegian industry to show for. This is far from what the end-users themselves expect, which is partly why some have decided to develop these solutions internally. Next, the value propositions are, for the most part, inaccurate in terms of what the interviewees prioritize. The frequency diagrams show that the technical features are the first concern. The value propositions focused on large impacts seem to be a bit too grand for the end-users to rely on their promises. One example is AVEVA, which states that 100s of millions could be saved on using their solution. How this is attained is much more difficult to comprehend. Lastly, the key partners are another area with contrast. The end-users desire the key partners to be the end-user's own software provider to ensure proper integration, regulatory agencies to ensure compliance and that requirements are met, and academia to ensure technological innovation and constant improvement of the solutions. The suppliers, on the other hand, have more focus on outsourcing the key resources they do not have internally rather than attaining them. The larger suppliers want to partner up with engineering companies to provide their customers with technical expertise, while end-users demand that the suppliers have this expertise in-house.

To summarize, as expected from a high-value industry there are plenty of aspects with compliance between end-users and suppliers. However, there are also areas of great contrast, especially in terms of allocating responsibility and influence. While suppliers desire to create solutions themselves that works for most companies, while relying on partners to handle the more intricate peculiar aspects of each solution, the end-users wish to be co-creators of their solution while relying on the supplier to have all resources internally to guarantee a strong synergy between software solutions and technical expertise.

4.2.6 General impression and observations

This section concerns findings and impressions that are attained through the analyses. In addition, aspects that are harder to quantify, like contradictions in expression and perspectives between end-users and suppliers, will be included here.

Exploiting the industrial opportunities

The general industrial attitude towards predictive maintenance is positive. Operators are interested in it and believe that in due time it will provide them with value. Government agencies understand that this is where the market is heading and see the value of it. Yet, there are still no large success histories from the Norwegian industry. When considering the general impression expressed by the interviewees, there is a lot of skepticism that hinders the progress of the technology. Pilot-projects missing promising results, lack of relevant industrial references, big promises without accompanying results, conventional culture. There are plenty of factors that are used to explain the restrictive position of the industry. When also considering some of the issues related to the technology, from the perspective of the operators, some quite prominent findings emerge. The general response from the end-users was that for PdM-solution to fully function, both in terms of proper development of algorithms, integration, and implementation, and in operation and improvements they must be developed either internally by the operator companies themselves or by an external company with all these competencies. This contradicts how many of the solutions are currently available, where several different actors are involved, with little understanding of each other's field of expertise. Further, the end-users had some issues with foreign software companies having seemingly little understanding, and especially little experience, from the Norwegian industrial environment.

Building on this, the best solutions in the general opinion of the end-users are developed internally in a company with extensive knowledge of both the technical aspects of maintenance and machinery and of the Norwegian industrial environment. Whether or not the PdM-initiatives result in major results immediately is not as important. To attain this comprehensive competence, it is more or less essential with considerable amounts of actual experience from the Norwegian industry. This will likely also have led to an extensive network and potentially a solid reputation. From the frequency analysis on desired attributes of PdM-solutions, technical reliability was the number one focus. When looking at the broader response given by the interviewees, the amount of reliability awarded by the end-user was seemingly strongly linked to a more subjective opinion on the solution. Participants pointed out the discomfort of engineers when being asked to initiate certain maintenance activities without being able to see how the prognosis was developed. Especially knowing that the analyses used to derive the prognoses were in many cases developed with little basis in the particular conditions and circumstances of their equipment. In other words, the reliability and corresponding credibility of the solutions are connected to the company and its processes. For companies with long seniority in the Norwegian industry, the situation is quite different. These companies, with a good reputation in the industry, already have the respect and trust of the operator companies. This puts them in a good position to be a leading company in the industry's technological development, particularly regarding predictive maintenance.

The industry is demonstrating its understanding of the extent of developing a well-function PdM solution with keeping such a positive attitude despite a lack of results. In addition, the participants in the interviews made it abundantly clear that a transition towards these types of technologies must be a gradual one for the industry to preserve and retain its commitment. Too big steps will put the industry back in a similar situation to the current one, with interest but little commitment.

Chapter 5

Validation

When conducting a validation on qualitative research study it is the reliability of its findings, analysis, and conclusions that is under investigation. This can be done in several ways, one of which is triangulation. Triangulation is a common method in social sciences of validating findings by looking at the compliance between different sources on the same phenomena (Rahman, 2012). For this thesis, there have been used several research methods, interviews with end-users, interviews with the government agency, literature review, workshops, and unstructured meetings. When looking at the impression and observations attained from the various research methods there is a prominent consistency in the findings. This consistency supports the validity of the thesis through triangulation.

There are several aspects to be discussed in terms of validation of the thesis. Despite an internal consistency in the report, the individual methods and tools used might still have limitations or other weaknesses. These will now be investigated. The main part of the data collection was done through qualitative semi-structured interviews. The interviewees were chosen based on their role in their company. Looking at the interviews with operator companies, there are some areas to inspect. Qualitative research is a resource-intensive methodology, demanding quality in the data collected. There were put significant considerations into choosing the right type of role of interviewees to match the objective of the thesis. Both internal discussions in Apply and some introductory conversations with external personnel were conducted to better understand the field and to identify the right participants. As seen in the methodology of the interviews, it was decided to go for mid-level management within operations and maintenance. This provides the position of being quite close to the hands-on technicians and understanding their work, while also having a managerial perspective. By exploring the findings from the interviews, clear compliance to these desired inputs is easily seen. However, several interviewees expressed that the response and reasoning would be quite different if the roles of the interviewees were different. This means that the findings might have been deviating from the current ones if technicians or higher-up management were being interviewed.

Another important aspect of qualitative research is the number of interviewees. In this thesis, 7 interviews have been conducted with 11 people in total. It can be argued that this is a too small number and hardly reflects a representative selection of the entire industry. However, the personnel involved all have extensive experience from the industry, some from several companies as well. When comparing the response to questions that were not specific to their particular company, there is strong compliance in the reasoning and arguments. This low variety in central aspects of the interviews indicates that the findings are in fact representative. Further, considering the individual interviews, the participants tend to repeat themselves. This repeating is seemingly increasing towards the last questions. This phenomenon is known as the saturation point (Saunders et al., 2018). When the interviewees repeat themselves it is a sign that the interviewee has provided all relevant information and that no further investigation is necessary. In other words, when the interviewee repeats themselves, this is because they do not have anything else to add. As mentioned above, this was the case in the interviews for this thesis.

A central part of the analysis was the appliance of business model canvas to demonstrate an idea and a generalized version of supplier companies. The reason for this method being used is explained in the methodology chapter. Despite the business model canvas being simple and well-known, it has some limitations. The main issue with the business model canvas is that it is a static representation of a business model. In other words, it does not account for change and strategies in a company. Further, the static nature of the BMC hides the interconnections between the blocks. Even though the BMC divides the company into nine separate blocks, these will interact in a real case scenario. By applying other, more extensive, and descriptive models these limitations could have been avoided. The strategy of companies and their internal interconnections are essential for their operations and should preferably be included in investigations on their business models, especially when working with rapidly developing and complex technologies.

Considering the input used to develop and reverse engineer the BMCs, there are some aspects to investigate. The generalized version for suppliers was based on open-source data, experience from end-users, and unstructured meetings regarding other matters. The content of the nine blocks in the BMC was only occasionally directly discussed. This means that the reverse engineering process was mainly based on indirect information. In addition, there was a significant difference between the companies included in the generalization. Hence, even though it was a representation of the companies included, some blocks may be too generalized and thus ending up in the middle of the companies. Yet, some of the blocks were more focused on than others, and therefore also a priority during the reverse engineering process. These blocks are more thoroughly examined and discussed. Moving on to the ideal BMC, some of the same issues are present. During the interviews, the nine blocks were not directly referred to. This was due to not limiting the interviewees in their response, complying with the nature of semi-structured qualitative research. Yet, it leads to the ideal BMC being developed based on impressions and indirect statements. A more precise ideal BMC could be achieved through focus groups or workshop sessions with the end-users.

Last in the validation is the impact the role of the author has had. By using a variety of action research from internally at Apply, a unique position for conducting the research is attained. This position did influence the research in many ways. First, Apply influenced the definition and perspective of the objective for the thesis to suit their own interests. If the project was initiated by another stakeholder in the field, it might have had a different perspective. Further, the people involved in the interviews were reached using Apply's own network. This means that the interviewees were all in some way or another linked to Apply through their role. This assures that the interviewees are likely to have a better understanding of the perspective of the thesis. This, in addition to them matching the desired role, strengthens the validity of their responses. One could argue that the fact that they all are linked to Apply in some way makes them biased. However, considering the number of partnerships and cooperation in the Norwegian industry, and the experience the participants have, it is likely that most companies would be linked to them in some way. Further, the interviewees hold important roles in their companies. Thus, professional integrity is expected, further strengthening the validity of their responses.

All in all, when conducting qualitative research on a complex and compound area like this, there are several aspects to consider. While there are some limitations to certain tools and methods used in this thesis in terms of their features and framework, the raw data attained from these are seemingly valid. Further, the perspective of the author and the sources for the raw data strongly influence the analysis and subsequent findings. If the perspective or the role of interviewees were different, the findings would also be different. However, considering the specific objective of this particular thesis, the data sources used are both genuine and credible.

Chapter 6

Conclusion

This chapter will revisit the main objective of the thesis and its corresponding research questions and directly connect them with their belonging analyses. By doing this, the objective will be answered based on the findings presented through the thesis. Yet, the field of predictive maintenance and its software solutions is far from fully explored and studied, especially considering it from the perspective of the Norwegian petroleum industry. Therefore, a section regarding recommended further work on the subject is included.

6.1 Main observations

To properly address the main objective from section 1.3, the following paragraphs will go through the main observations corresponding to the four research questions. Further, an encapsulation of the key takeaways is presented.

Research question 1

Considering research question number 1, regarding the end-users view on PdM software. From the interviews with the operator companies, extensive insight into the perspective and attitude on PdM from end-users were attained.

As an overall impression, the end-users are unanimously positive to PdM, and believes that it will become a valuable maintenance strategy. They all agreed that a well-functioning PdM software is superior to the traditional and conventional maintenance strategies commonly used up until now. At the same time, the end-users also agree on there being some substantial challenges with the PdM solutions. The nature of these challenges vary somewhat, although, they mainly concern issues related to the industrial context like regulatory requirements and competence, and specific technical attributes like algorithms and amount of data. Still, the end-users remain enthusiastic and support commitment and efforts on developing PdM solutions further.

Research question 2

Moving over to the second research question regarding investigating the business models of suppliers of PdM-solutions. Despite it being termed a research question, it is actually more of a descriptive effort. From the open-source data found on a selection of PdM-supplier's websites, in combination with the information collected through unstructured meetings alongside the knowledge of the suppliers held internally at Apply, a generalized business model canvas has been derived.

The impression attained from the generalized business model canvas is that it is not particularly precise. There is little specialized emphasis for the Norwegian business environment. The value propositions concern large-scale impacts. The customer segments are a broad mass market. Next, the reverse engineering showed that the suppliers, especially the larger ones, prefer to allocate away the technical services associated with the PdM-solutions to partner companies. Further, there are some degree of co-creation and flexibility in solution packages.

Research question 3

The third research question addresses the compliance between end-users and suppliers of PdM-solutions. This is explored through the comparison between the ideal and generalized business model canvas', and through comparing the impressions attained through interviews and meetings.

When considering the larger context of predictive maintenance, the suppliers and the end-users agree. The attitude for both is unanimously positive and they agree that the technology facilitating for predictive capabilities is soon to be a regularity in maintenance systems. However, there are some central aspects with substantial disparity between end-users and suppliers. As seen in the interviews, the end-users favor solutions that are tailored for them and their industrial circumstances. Further, they seek reliable references that can provide proof of concept to solutions. Many suppliers do not recognize the importance and consideration this that end-users wish they assigned to it, and downplay their concern. Another central disagreement is regarding the allocation of resources activities. End-users made it abundantly clear that it is favorable when their suppliers have all the required resources for PdM solutions internally rather than them being dispersed. Suppliers, on the other hand, tend to favor allocating much of its expertise and resources away.

Research question 4

The fourth, and last, research question explores the opportunities that emerge from the findings in the analyses. By considering the findings from the other 3 research questions

As mentioned, there is a large enthusiasm for predictive maintenance in the Norwegian industry. This enthusiasm can be exploited by using the momentum it brings to launch initiatives and projects. There is a prominent market pull for PdM in the Norwegian industry, however, it is not indifferent who delivers the solutions. The end-users seek solutions provided by actors with knowledge on both the technical aspects and of the industrial context. This is where opportunities emerge. The positions that Apply and other engineering companies have in the Norwegian industry are unique. These companies have a large network, extensive knowledge, and comprehensive technical expertise. More and more are also increasing their efforts on digital operations and software solutions. At the same time, the desire from their customers, the operator companies that develop and deliver software for PdM-solutions should have all these features. This leads to the opportunity of engineering companies internally developing PdM solutions. Given that these often have many of the attributes favored by end-users, they retain a genuine market opportunity through their position.

Addressing the overall objective

In section 1.3, the overall objective of thesis was presented. There, the thesis was defined to be aimed at analyzing the market for software solutions for predictive maintenance currently available in the Norwegian industry. This was to be attained particularly by investigating the business models of supplier and its compliance with the end-user. Finally, the findings should be used to explore opportunities in the current market. This thesis has been a qualitative research, heavily based on a set of semi-structured interviews with end-users.

Through the research, a lot of information on the current market situation for PdM-solutions available for the Norwegian industry has been processed and analyzed. The overall impression is that even though there are some major challenges and obstacles to overcome before PdM- solutions can meet their full potential a strong enthusiasm and positivity are prominent. From the analysis, it became clear that even though the suppliers are professional companies, there remains gaps and unrealized potential in the solutions. The most significant differences between suppliers and end-users are regarding specialization on particular industrial circumstances and allocation of resources and activities. Further, when considering the desired of end-users to the industrial context, a indication towards the opportunity of engineering companies internally developing PdM solutions becomes evident.

6.1.1 Reflection on research

This thesis was initially aimed at investigating the market for PdM software solutions. This being a complex field, it was decided that qualitative research would be best suited. Given that the thesis has been in conducted from internally in an engineering company, it has been natural to exploit the possibilities this brings. Thereby, Apply's internal expertise and extensive network in Norwegian industry has been strongly utilized, proving very valuable.

The methodologies applied in the thesis have proved effective. The semi-structured interviews provided an open discussion on a predetermined subject without strict restrictions to reasoning and answers, while unstructured meetings contributed with more general impressions on attitude and approach of suppliers. The workshops utilized the internal expertise of Apply in processing the results, while other recognized qualitative research methods were applied to process data into intuitive and clear information. However, there are some limitations to certain methods used. The BMC is a static model with no fixation on change and strategy, and the interviews were likely influenced by the role of the interviewee, and would presumably turned out different with participants from other positions and perspectives.

Initially, it was expected that the research would detect gaps in the current solutions for predictive maintenance. This expectation was based on the impression from the initiators from Apply and on the literature on the subject. The findings from this research correspond well with these expectations. Further, the aim of the thesis was to provide Apply, and the industry in general, with information that could be used to facilitate more accurate and targeted efforts on improving these solutions for the end-users.

This thesis confirm the preexisting perception of software solutions for predictive maintenance. Namely, that this field possess areas of unrealized potential and that these are not solely in terms of a technical character. Further, the observations indicate the preferred basis of these solutions, derived from the end-users' perspective. This thesis is a helpful contribution in the development and optimization of software solutions for predictive maintenance, particularly in the Norwegian industrial context.

6.2 Further work

Based on the observations from the analysis and conclusion, some areas of particular interest are recommended to be assigned due consideration and further studies:

1. **Study on internal development of PdM-solution**
   Engineering companies with an existing strong position in the Norwegian industry should investigate their possibilities to develop PdM-solutions internally. This includes a mapping of the required resources and how these could be obtained. The most crucial resources will be competence and data. Competence will likely be a long-term initiative, while data access can be attained from the company's own network. In addition, an

extensive ideal business model for the engineering company should be developed to conceptualize the target situation, and how to get there.

2. **Industrial, and company-specific, initiative in future competence need** The technology used in predictive analytics is constantly undergoing further development. To remain competitive there is no doubt that there must be a simultaneous constant renewing of competence. Studies addressing what this competence is and how it can be achieved are necessary, both for the individual companies and also for the entire Norwegian industry at large. The Norwegian petroleum industry is at the forefront of technological innovation, but with the acceleration of technology development, there must be a continuous effort to attain competence to remain there. This must be a cooperation between the companies, the regulatory agencies, and academia.

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