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A maturity analysis of Høglund AS' use of predictive maintenance in their cloud service system: A case study

By

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(June 2021)

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Abstract

As the fourth industrial revolution is gaining traction in most industries, with digitization, predictive maintenance (PdM), artificial intelligence, and cyber-physical systems it is important for most of the companies that want to be market-leading to be a part of the revolution commonly known as industry 4.0. The shipping industry is no exception and is also undergoing changes with the adaption of industry 4.0. Industrial sectors that depend heavily on physical assets, e.g. manufacturing and transportation industries, have a special interest in PdM in order to maintain reliable, safe and available assets. Therefore, we are eager to gain the benefits from adopting predictive maintenance.

However, there are several challenges to implement PdM into existing industrial installations and commercial solutions:(1) lack of standards, (2) lack of maturity modes, (3) lack of commercial reliable products and services. For example, Høglund AS provides cloud services for the shipping sector and aims to adopt PdM to provide more intelligent and cognitive tools for their customers. To do this they would like to assess the maturity of its services in combination with the physical assets of the customer and determine what should be considered to reach a higher level of cloud services.

Therefore, the purpose of this thesis is to assess the current maturity level of Høglund AS and work out what needs to be improved in their systems to reach a high level of PdM maturity so their cloud service system can be used for predictive maintenance.

To be able to fulfill the purpose, Høglund was purposefully selected as a case study for this thesis, and the case study research method was applied. Through this thesis, five types of analysis were applied: (1) system of systems (SOS), (2) Needs and requirement analysis, (3) Maturity analysis, (4) Gap analysis, and (5) SWOT analysis.

To conduct the five analysis methods as stated above, data was required. The data was collected by the use of several methods. First, research in the existing system that Høglund is operating was carried out. Semi-structured interviews with the main stakeholders of the system were conducted. This was followed by a questionnaire about the current state of the system that was given to both Høglund and its customers. Last, diesel engine reliability data was obtained. All the collected data was concentrated and used for further analysis. The results from some of the analysis methods also served the purpose of data for the next analysis method.

The key results and findings of the analysis are as follows:

1. Cloud service providers like Høglund has to build customized maturity model, as the general maturity models (e.g. the one developed by PwC) have limitations when it comes to detailed specifications.

2. The maturity model for cyber-physical systems requires considering both the cloud service provider and their customer. It is clear from the results that a combined maturity model provides higher maturity levels.

3. Cloud service providers shall focus on full sensorization and data collection to support the analytics of interest. This should be based on the prioritization table that can be derived from the Gap analysis.

4. Cloud service providers shall consider Gap and SWOT analysis to connect the maturity studies and findings with strategic planning.

5. Maturity studies shall be utilized to support the decision-making process and it shall be part of the continuous improvement processes.

All in all, Høglund has a lot of the necessary infrastructure to offer PdM to their customers. However, they are underdeveloped in certain areas, like the data they collect and the missing data analysis. The overall maturity level Høglund obtain at the moment is 3 out of 4. By allocating resources to develop their cloud service system further, they will most likely reach a level 4 if they want to.

Acknowledgement

I would like to express my gratitude to everyone who has helped me accomplish this thesis. A special thanks go to professor Idriss El-Thalji for your guidance and insights.

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Oscar Holmås
Stavanger, 14.06.2021

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Abbreviations:	Word:
AI	Artificial intelligence
ML	Machine learning
ANN	Artificial neural network
DL	Deep learning
CM	Condition monitoring
PdM	Predictive maintenance
PdM 4.0	Predictive maintenance level 4
PM	Preventive maintenance
IoT	Internet of things
SPM	Ship performance monitoring
IaaS	Infrastructure as a service
PaaS	Platform as a service
SaaS	Software as a service
MTTF	Mean time to failure
MTBF	Mean time between failure
API	Application programming interface
DB	Data base
IT	Information technology
ICT	Information and communication technology
SH	Shareholder
Req	Requirements
Crit	Criteria
SOS	System of systems
OREDA	Offshore and onshore reliability data
ISO	International Organization for Standardization
RPM	Rounds per minute
R&D	Research and development
HSE	Health, safety and environment
ERP	Enterprise resource planning
GUI	Graphic user interface

Chapter 1

Introduction

1.1 Industry Background

As the world industry is making its move towards a more digitized form utilizing Internet of Things (IoT), cloud computing, and cyber-physical systems, it is more important than ever for businesses to keep up. This shift is considered by some, one of the most important industrial shifts since the introduction of computers and the wide use of the internet. IoT systems, cloud computing, and cyber-physical systems are only a few of the pillars that make up what we call Industry 4.0. The possible advantages of incorporating some of these systems are many, such as better efficiency, productivity, and a broader and more informed foundation to make decisions (Naveen Kumar 2014). If done with the right intentions and in the right way, Industry 4.0 will have the ability to disrupt how a business operates and evolve (Gjoko Muratovski 2020). The main objective of implementing Industry 4.0 technology is to collect the necessary information to make better decisions and automate the work processes in a business's operation (Martin Luenendonk 2019).

Increasingly, businesses adapt and incorporate Industry 4.0 technology. This results in a substantial amount of data being generated by businesses and people worldwide for analysis. According to Forbes, (Press 2020), the amount of data generated in 2010 was about 1.2 zettabytes (1.2 trillion gigabytes). This number increases rapidly every year, and the expected amount of data created in 2025 is 175 zettabytes. With this amount of data generated, the industry must develop methods for analyzing the data smoothly and seamlessly. By 2025, it is estimated that about 30% of the data generated requires real-time processing (IDC 2018).

With the introduction and further development of IoT, real-time data processing and analysis, new and exciting possibilities present themselves. Like for example, the possibility to monitor an asset's health and condition. This is what is known as condition monitoring (CM). The data collected from the sensors placed on the asset could then be analyzed using various methods to predict its future state. The analysis results could then be used to plan and predict future maintenance needs for an asset. This is what we call predictive maintenance (PdM).

In 2018, PWC made a maturity framework and surveyed 280 companies in Belgium, Germany, and the Netherlands to check how PdM-ready these companies are. The survey results were split between four levels according to how PdM-ready the companies are with the highest mark called PdM 4.0. The maturity levels and criteria for each of them are shown in figure 1.1 below.

Capability	1. Visual Inspection	2. Instrument Inspection	3. Real Time Condition Monitoring	4. PdM 4.0
Processes	- Periodic inspection (Physical) - Checklist - Paper record	- Periodic inspection (physical) - Instruments - Digital recording	- Continuous inspection (remote) - Sensors - Digital recording	- Continuous inspection (remote) - Sensors and other data - Digital recording
Content	- Paper based condition data - Multiple inspection points	- Digital condition data - Single inspection point	- Digital condition data - Multiple inspection points	- Digital condition data - Multiple inspection points - Digital environment data - Digital maintenance history
Performance Measurement	- Visual norm verification - Paper based trend analysis - Prediction by expert opinion	- Automatic norm verification - Digital trend analysis - Prediction by expert opinion	- Automatic norm verification - Digital trend analysis - Monitoring by CM software	- Automatic norm verification - Digital trend analysis - Prediction by statistical software - Advanced decision support
IT	- MS Excel/MS Access	- Embedded instrument software	- Condition monitoring software - Condition database	- Condition monitoring software - Big data platform - Wifi network - Statistical software
Organisation	- Experienced craftsmen	- Trained inspectors	- Reliability engineers	- Reliability engineers - Data scientists

Figure 1.1: Level of PdM maturity, [made by author, based on PWC's maturity framework (Michel Mulders 2018)]

From the survey, they found out that only 11% of the businesses had reached PdM 4.0. In their 2017 survey, they found the same numbers. This is even though 60% of the respondents in the survey said they plan to get to a level PdM 4.0. Most of the other recipients stated the lack of money due to not planning for PdM 4.0.(Michel Mulders 2018) The same survey found that the improvements from implementing PdM 4.0 were, on average, a 9% improvement in uptime. This is a significant improvement that has the potential to save a company waste amounts of money. This is especially important in a country like Norway, where the labor cost is high.

The shipping industry is not different from other industries in terms of experiencing downtime due to unplanned maintenance. According to "The Swedish Club," a ship insurance company, about 2% of their insured fleet experienced main engine breakdowns in the 2012 to 2014 period (Club 2015). They insured in total 5,467 ships, which means 118 of the ships experienced main engine breakdown in this period (Club 2015). With an average cost of fixing a main engine breakdown of 545,000 USD (Club 2015), the total cost is estimated to be around 64,3 million USD. If everyone of their ships had implemented PdM 4.0 and gained the 9% improvement in up time, they could have saved about 5,8 million USD. Extrapolating these numbers for the cargo shipping industry as a whole, we can clearly see the huge saving potential. In 2019 there where registered about 53,000 merchant ships, meaning a full implementation of PdM 4.0 could save the industry about 56 million USD annually in main engine repair.(Statista 2019) Keep in mind that these numbers are only regarding the main engine, and does not show the potential savings for the rest of the machinery onboard the ships. The saving potential for the industry as a whole in terms of increased up time for machinery based on numbers from "The Swedish Club" and "Statista" is shown in figure 1.2 below. Also keep in mind that these numbers only display the cost of repairing the assets, if we factor in the lost revenue by not being able to operate when the machinery is getting repaired, the numbers are way higher.

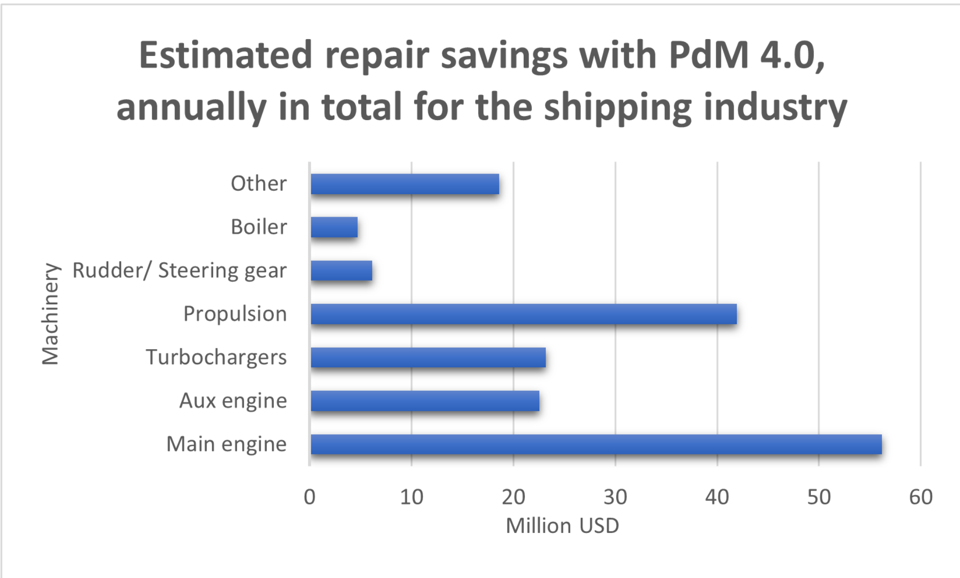

Figure 1.2: Savable annual revenue if PdM 4.0 gets fully implemented in the shipping Industry, [Calculated and made by author]

In addition to the corrective maintenance costs that companies can save by implementing PdM, other factors speak towards PdM. For example, lifetime expansion of components and assets, reduction in predictive maintenance, and asset performance enhancement. These are all a part of a bigger picture that makes up the total cost-benefit of PdM.

1.2 Company background and problem presentation

1.2.1 Company background

This thesis is a maturity analysis of Høglund Marine Solution AS regarding their adoption of Industry 4.0 and how PdM-ready their cloud services are. Høglund is a company mainly divided into three divisions, all relating to the shipping industry. As shown in figure 1.3 below, the divisions are Automation, Retrofit, and Energy. As this thesis mainly revolves around automation, the services offered in this branch are also shown in the figure.

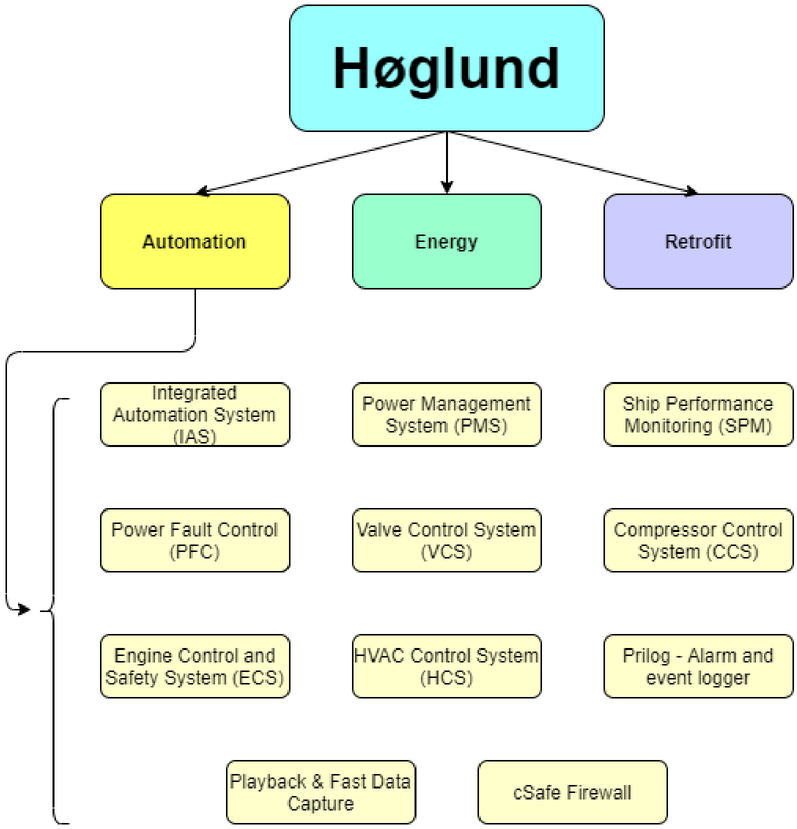

Figure 1.3: Overview of Høglund's business structure and the services offered in their Automation branch, [made by author]

Høglund offers a Cloud solution to their customers with many of the features shown in figure 1.3. They also offer live data that Høglund could upload to the cloud with a one-minute frequency. As Høglund does not own the ships themself but operates as a service company, they have connected the author of this thesis with one of their customers, called Utkilen. Utkilen is a shipping company owning several cargo ships that goes in international traffic. As access to data is needed to assess the system's maturity and look into solutions to improve it, Høglund has granted the author access to their cloud services for some of the Utkilen ships. Mainly the focus will be on one of Utkilen's ships called Mostraum. Mostraum is a 129.4-meter long cargo ship built-in 2019. It is shown in figure 1.4 below.

Figure 1.4: Mostraum (Utkilen n.d.)

Utkilen has opted to implement many of the features that Høglund offers on Mostraum. The most interesting with the thesis in mind is the Ship Performance Monitoring System (SPM) they have installed. This system will relay the data of the main engine, diesel generators, propulsion, etc., from the ship to the Høglund cloud every one minute. For limiting purposes, the main focus will be on the data collected for the main engine. The main engine data mainly consist of temperature, pressure, RPM, load, engine torque, and torsional vibration.

1.2.2 Problem presentation

As stated in section 1.1, there is much to gain from reaching a PdM 4.0 level of maturity, both in terms of cost-benefit and improved machinery reliability onboard the ships. As the shipping industry‘s Industry 4.0 maturity increases, service companies like Høglund have to mature as well. If they fail to do so, they might miss out on great opportunities.

The problem that Høglund is up against is to know the way forward to reach a maturity level of PdM 4.0, as shown in figure 1.1. Today, the data collected by Høglund is not being analyzed and used for maintenance decisions by their customers. The only current use of the data is for direct monitoring of the ships from onshore and reports. Therefore, Høglund must answer some fundamental questions for Høglund to know how to reach PdM 4.0 in the future. For instance: at what maturity level is Høglund as a company now, and how mature is their cloud service? Is the data collected by Høglund sufficient for analysis in a PdM fashion? If so, How could the data be analyzed for it to be helpful in terms of PdM? If not, what needs to be done to get to that level?

1.3 Research question

- How could Høglund Marine Solutions' cloud service reach a maturity level of PdM 4.0 so it can be used for predictive maintenance in the shipping industry? -

To answer this question, we need to assess the current level of maturity of Høglund's cloud service and then identify the technical specifications to level up the maturity level in terms of process, content, performance measures, IT, and organization.

1.4 Methodology

To answer the research question, several methods have been utilized. Below the methods that have been used are shown, followed by a short explanation of each of them and their purpose.

1. Data collection
2. Systems of systems
3. Needs and requirements analysis
4. Maturity analysis
5. Gap analysis
6. SWOT analysis

Before any of the analysis methods can be carried out, the data collection needs to take place. There are several reasons why this needs to happen in this order. First, an overview of the current state of the Høglund cloud system and how it is operating is vital to understand to know how to move forward with the thesis. Second, to perform the analysis methods, data is required and needs to be collected.

To collect the necessary data, several methods have been used. First, research in the existing cloud service system that Høglund is operating today was done. Second, several semi-structured interviews with the main stakeholder of the Høglund system was conducted. This was followed by a questionnaire sent out to Høglund, Utkilen, and one other operator company similar to Utkilen. Last, research to gain general reliability data about the main diesel engine in large cargo ships was done. More details about the data collection can be found in the data collection chapter.

With the collected data and further research in the shipping industry, a system of systems (SOS) diagram was made. This was done to better understand and show the contribution that Høglund could have if they implement PdM to their cloud service. It was also done to show how Høglund could fill in an existing gap in the market using Utkilen (one of Høglund‘s customers) as an example.

After the SOS diagram was filled in, a needs and requirement analysis was conducted. This was done using the collected information from the semi-structured interviews and questionnaire. The purpose of the needs and requirements analysis was to gain an overview of the needs that the main stakeholders have concerning PdM.

To answer the research question, a maturity analysis of the current state of Høglund and one of its customers had to be conducted. This was mainly achieved by utilizing the information collected from the questionnaires. An additional company was assessed to increase the reliability of the finding in terms of maturity at the customer's side. The chosen company for assessment was Dolphin drilling. Even though Dolphin drilling is not a shipping company, they use large diesel engines onboard their platforms for generating electricity. This made them comparable to Utkilen.

After the maturity analysis was conducted, the gap between the actual maturity and full PdM implementation can be analyzed. By having the maturity level of Høglund before the gap analysis, it is possible to know precisely what they do have and what they do not have. This enabled data-driven decisions when looking at what improvement is needed to reach full implementation of PdM.

Last, a SWOT analysis was conducted. This was done to gain an overview of the strengths, weaknesses, opportunities, and threats that Høglund is up against. When conducting a SWOT analysis after a maturity and gap analysis, a more holistic approach was chosen. This was done to raise awareness of the opportunities and threats beyond just the technical aspects of PdM.

1.5 Scope of the Thesis

As this project is a master thesis, it is limited in terms of time and available resources. The time frame for the thesis is set to be from the 15th of January to the 15th of June 2021. This time frame will affect how in-depth it is possible to go into each of the topics in the thesis. The research question has been answered as thoroughly as possible with the present limitations in mind.

The availability of resources has been affected due to the global pandemic Covid-19. This has made it challenging to schedule physical meetings with companies and restricted access to resources like people and equipment at the university. These constrictions are, for example, the lack of computing power for data collection and cleaning and expertise help.

At the beginning of the thesis, the object was to use the data that Høglund is already collecting for analysis using machine learning. This proved difficult as Høglund, for the most part, only collects data points that change in value at a rapid frequency. For example, pressure and temperature values. The goal is still to get Høglund to a maturity level of PdM 4.0. With the missing data points, the whole system had to be evaluated from the bottom up. This is so Høglund can be left with all the necessary information and make data-driven decisions in their pursuit of PdM 4.0.

Given the constrictions discussed above, as well as other limitations, the thesis had to be limited. A short list of the limitations that are done to complete the thesis is listed below.

1. Technical details surrounding sensors and software and what to choose for improving the maturity are not included in the thesis.
2. Technical details surrounding AI and how it is used explicitly in PdM algorithms are not included in the thesis.
3. Technical details on how to diagnose machine health are not included in the thesis.
4. A cost-benefit analysis of the impact of implementing PdM to Høglund‘s portfolio is not included in the thesis.
5. A generalized method that any company can utilize for assessing what specific equipment and software they are missing is not included in the thesis.
6. The maturity framework used in the thesis is not made by the author but based on the framework made of PWC and Mainnovation (Michel Mulders 2018). This was done to ensure the reliability and validity of the framework and utilize the given time most effectively.

1.6 The structure of the thesis

The thesis structure is based upon the recommended guidelines given by the university and guidance from the supervisor. However, some of the sections have been modified to fit this case. As shown in the list below, the main structure of the thesis is listed and outlined. Chapter 1 contains an overview of the thesis in general. This includes background, problem presentation, research question, methodology, the scope of the thesis, and a project plan. Chapter 2 consists of the research design and methodology that is used in this thesis. Chapter 3 Contains the theoretical background that needs to be discussed and understood for the analysis to occur. In chapter 4, the necessary data needed for the analysis is collected. The methods of collection and how and when it is done is disclosed in this chapter. In chapter 5, the analysis takes place. Here the 5 chosen analysis methods are carried out. In chapter 6, the discussion takes place. This includes the validity and reliability of the finding in the analysis and a discussion of the 5 analysis steps. Last, in the discussion chapter, further work is suggested and discussed. In the final chapter, the conclusion for all 5 analysis steps is given and answers to the research question.

1. Introduction
   - Industry and company background
   - Problem presentation and research question
   - Methodology
   - Scope of the thesis
   - Project plan
2. Research and methodology
   - Research design
   - Research methods and Techniques
3. Theoretical Background
   - Maintenance strategies
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4. Data Collection
   - Research in the Høglund cloud service
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   - Systems of systems (SOS) diagram
   - Needs and Requirements
   - Maturity analysis
   - Gap analysis
   - SWOT analysis
6. Discussion
   - Validity
   - Discussion of the 5 analysis steps
   - General reliability
   - Further work
7. Conclusion
   - Research question answer
   - Conclusion to the 5 analysis steps

1.7 Project plan

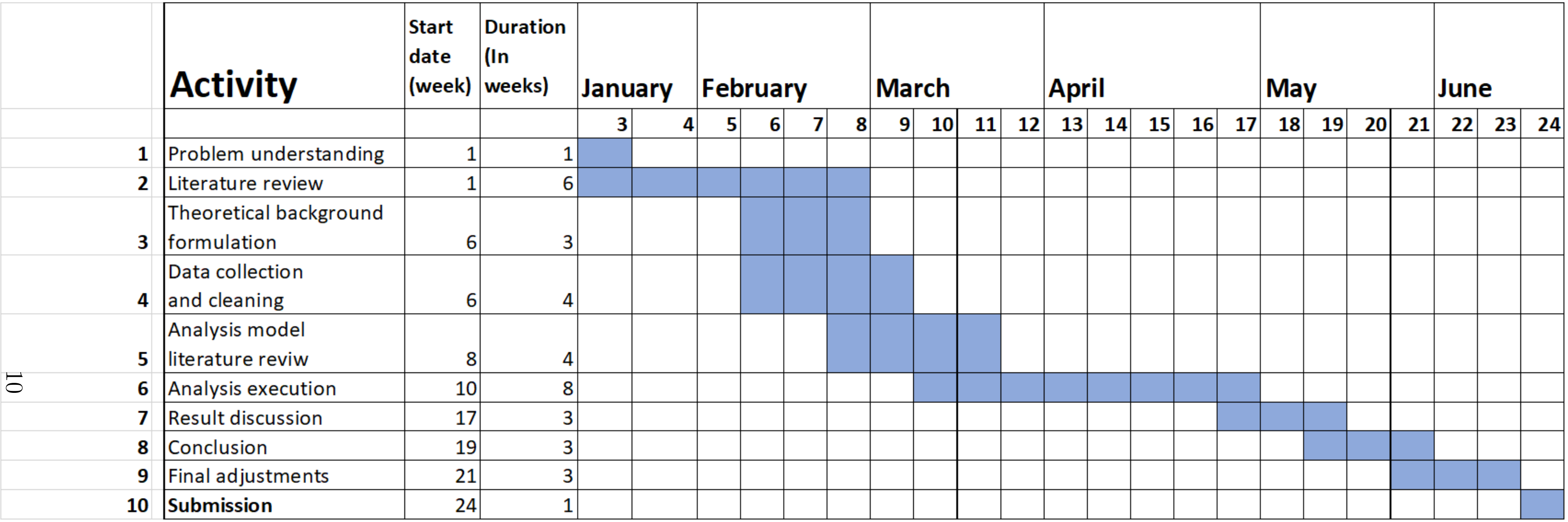


Figure 1.5: Gantt chart of project plan, [made by author]

Chapter 2

Research and methodology

This chapter contains the research design and methodology used for answering the research question previously stated in section 1.3. Below is the research's purpose, the steps taken to answer the research question, and the research philosophy. In addition, the data sources, data collection methods, data analysis methods and measure for ensuring the reliability and validity of the data and analysis is defined.

2.1 Research Design

The purpose of this thesis is to conduct a case study on how Høglund Marine Solutions' cloud service could reach a maturity level of PdM 4.0, so it can be used for predictive maintenance in the shipping industry.

To perform the case study, the maturity level of both Høglund and their customers regarding PdM readiness has to be known. This is the first step for figuring out what needs to be done for Høglund to reach a level PdM4.0.

For assessing Høglund and its customers' maturity, a combination of data collection methods is used. First of all, a series of interviews were conducted with both Høglund and Utkilen (customer of Høglund). Further, access was gained to the systems that Høglund is operating where all the customer cloud service data is stored and available. A survey with questions derived mainly from the PdM maturity level framework of PWC (Michel Mulders 2018) has also been made and answered by both Høglund and Utkilen. Using these methods in combination will enable the placement of Høglund and its customers at a maturity level from 1 to 4. Given a result of anything less than level 4 on both sides, a continuous improvement process will occur until suggestions on how level 4 can be obtained is present. For structuring the research, a six-step framework for case studies (Yin 2013) has been used and is shown in table 2.2 below alongside each step's primary function, what the steps consist of, and related research philosophy.

As the main objective of the case study is to determine the level of maturity of Høglunds cloud service in terms of PdM abilities, most of the research will consist of

Table 2.1: 6 step framework for conducting a case study, [made by author]

Steps	Main function	What	Related philosophy
1: Understand the case	- Analyse the case and its context - Current state of both Høglund and customer	- Main maintainable assets (e.g main engine) - Current use of PdM - Maintenance - Systems that are already in place	- Pragmatism - Critical Realism
2: Plan and design for execution	- Construct questionnaire based on existing frameworks for PdM. - Research existing systems	- Extract needs and requirements - Framework development/ adjustments	- Constructivism - Interpretivism
3: Prepare research methods	- Use survey, interview and literature review	- Survey model development	- Constructivism - Interpretivism - Positivism
4: Data collection	- Obtaining necessary data for pinpointing maturity level	- From survey, existing cloud service, interviews and literature	- Qualitative
5: Analyse the collected data	- Maturity and improvements	- Perform maturity analysis based on data findings - Perform gap analysis - Perform SWOT analysis	- Positivism - Constructivism - Interpretivism
6: Report of findings	- Write up findings and look for improvements	- Use results of analysis for assessing further work that can be done for closing gap and improving maturity level	- Interpretivism - Positivism

quantitative research and analysis. Below, a more detailed description of every step from table 2.2 is shown in a list format.

- Step one; Understanding the case.

  To be able to answer the research question, it is essential to start with understanding the case. First of all, research on the existing solutions that Høglund offers was conducted. This includes familiarization with the cloud service they offer, its functionalities as well as its shortcomings. Interviews with Høglund and Utkilen were conducted to better understand the needs and requirements from both sides and understand the system that is already in place. Recorded historical data was collected, and research resources were used to find cases of failures captured by the historical data that later could be used for analysis.

- Step two; Plan and design for execution.

  When planning how a questionnaire should be formed, it is crucial first to structure the needs and requirements of both Høglund and Utkilen. As the survey is mainly for assessing maturity, it is based on a maturity framework from PWC. Another point in this step is to do extensive research of the existing system for easier placement of the Høglund on the maturity framework and not using the questionnaire for unnecessary questions.

- Step three; Prepare research methods.

  The primary method will be preparing the survey as well as conducting the interviews. In this step, the main objective is to construct a set of questions that are later used for placing Høglund and its customers on a scale of maturity. The questions are derived from a premade maturity framework developed by PWC (Michel Mulders 2018). However, some additional questions are made for clarification purposes and additional helpful information. The questionnaire is made using google forms as this is an easy and structured way of obtaining the information needed from both Høglund and Utkilen. Furthermore, since Høglund and Utkilen are on opposite ends of the customer-provider relationships, custom-made questionnaires are made for both.

- Step four; Data collection.

  The data collection is mainly done by sending out the survey to both Høglund and Utkilen. Another questionnaire is also sent out to Dolphin Drilling for verification purposes and additional information. Other sources of data collected are interviews and research in the cloud service that Høglund already is providing.

- Step five; Analyse the collected data.

  With fully answered surveys combined with research on existing solutions, both Høglund and Utkilen are placed on a scale from 1 to 4 on how mature they are in terms of PdM. With knowledge of where they are to this date, a gap analysis is conducted to identify what is lacking for Høglund to reach a level 4. When the gap analysis has been performed, a SWOT analysis with a holistic view is conducted.

- Step six; Report findings.

  A total overview of the current state of maturity for both Høglund and Utkilen is available in this last step. Then, further investigation and analysis will investigate how the criteria' gaps could be closed and improved.

2.2 Research Methods and Techniques

Below in table 2.2 the research methods and techniques use in this thesis are shown. This table shows how the information is collected and what methods and techniques are used. It shows the process that is followed to be able to perform all five types of analysis. First, the research steps are defined, followed by the data source. The following section shows what method is used to collect the necessary data. When these three steps have been performed in that order, all the information is there to perform the analysis. The analysis methods used in this thesis are Systems of systems diagram, needs and requirements table, maturity analysis, gap analysis, and SWOT analysis. In the last column, the actions taken to ensure the reliability and validity of the research are shown.

Table 2.2: Detailed research methods, [made by author]

Research steps	Data source	Data collection	Data analysis	Reliability and validity actions
Research Høglund`s position in the shipping industry	Høglund, Utkilen and literature	Semi structured interview with both Høglund and Utkilen	System analysis, SOS diagram	Comparison with existing systems, literature review
Extract needs and requirements from stakeholders	Høglund and Utkilen	Phone interview with both Høglund and Utkilen	Needs and requirements analysis	Interview with several people at Høglund as well as Høglund's customer and similar operators
Place both Høglund and customers on maturity scale	Høglund, Utkilen and similar operator as Utkilen	Survey made of me based on PWCs PdM4.0 framework	Maturity analysis	Results verified by Høglund. Increased reliability by surveying multiple firms.
Conduct a gap analysis	Results from maturity analysis, PWC framework, ODERA	Maturity analysis, existing system	Gap analysis	Results verified by Høglund.
Holistic SWOT analysis	Maturity analysis, gap analysis, Literature review	Results of previous analysis, further investigation towards strengths, weaknesses, opportunities, and threats	SWOT analysis	Results verified by Høglund.

Chapter 3

Theoretical Background

To provide a sufficient theoretical background about the topic, the asset, and the analysis method, this chapter starts with the different maintenance strategies followed by theory about Industry 4.0 and last a section on theory about the analysis methods.

3.1 Maintenance strategies

As maintenance is vital for getting the most out of your assets, the asset owners need to have a proven relationship with the different maintenance strategies and how they function. As a rule of thumb, we can divide maintenance into three categories as shown in figure 3.1 below; these maintenance strategies have been developed as the need for them has presented itself and technology has allowed for it. It is also important to keep in mind that the different maintenance strategies serve different purposes, meaning it would not always be beneficial to use the most sophisticated method. This depends on the complexity of the asset, the available technology, maturity of the company, cost-benefit, and the consequences of a potential breakdown.

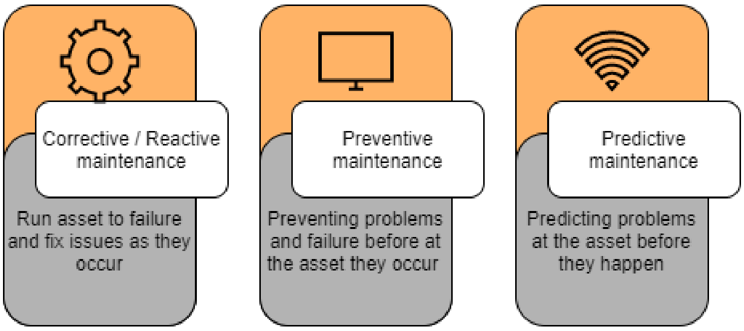


Figure 3.1: Maintenance strategies, [made by author]

3.1.1 Corrective/ Reactive maintenance

Corrective or reactive maintenance is a maintenance strategy in its simplest form. It simply is the strategy of running or operating the asset to break down and then repairing it (Deighton 2016). This strategy has certain advantages over preventive and predictive maintenance. First of all, as can be seen from figure 3.2 below, there are low costs associated with preventing failure. On the other hand, the repair cost is often higher. This gives an overall high total cost when operating only with a corrective maintenance strategy. Since the assets are run until breakdown occurs, the entire lifespan of the components is utilized.

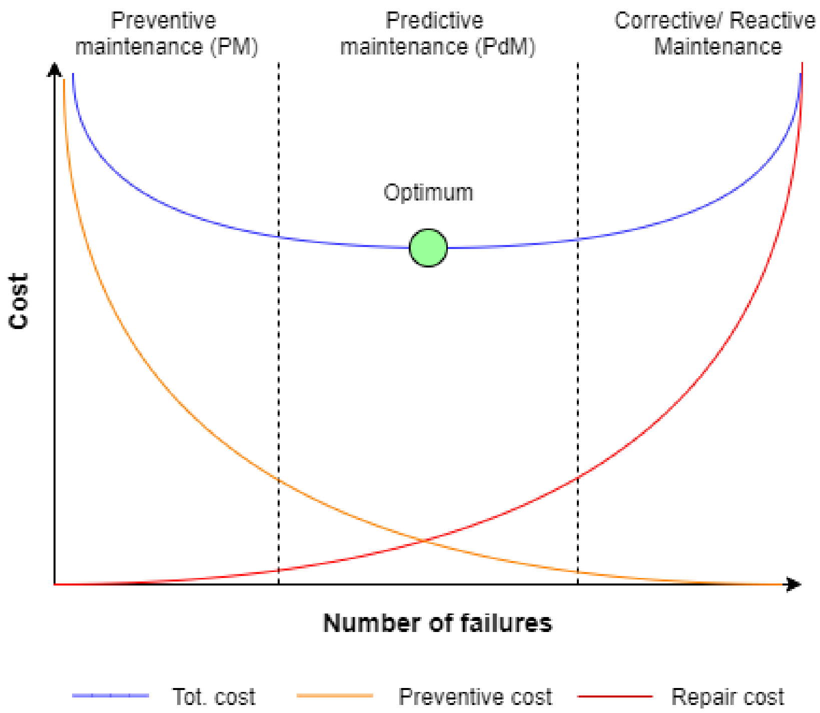


Figure 3.2: Cost-benefit of corrective, preventive and predictive maintenance, [made by author]

Corrective maintenance is an often-used strategy when there is a redundancy in the system or the consequences of a potential breakdown are limited. However, it is important to keep in mind that this strategy often leads to more repair work than other strategies. When a component fails, it often fails in a catastrophic manner leading to other components failing. Since there is no root-cause analysis when operating with a corrective maintenance strategy, the broken component is replaced or fixed, leaving the breakdown's cause. This often leads to an increase in breakdowns. Another disadvantage of corrective maintenance is that there is no way to plan when the maintenance should be done. This often leads to increased repair costs. When operating with a corrective maintenance strategy, it is crucial to have excellent spare part management and access to the expertise to repair the asset when it breaks (Ben-Daya 2016).

3.1.2 Preventive maintenance

Preventive maintenance (PM) is one of the earliest forms of maintenance strategies and is divided into two sub-categories, nonintervention type and intervention type activities (Deighton 2016). The objective of PM is to keep assets in a working condition by the use of routine maintenance to avoid unplanned downtime and unexpected repair cost(Ben-Daya 2016). Even though preventive maintenance is an old strategy it is widely used in all sorts of industries around the world. As can be seen in figure 3.2 the PM strategy is at the opposite end of the cost-benefit paradigm with a higher maintenance cost than corrective maintenance, but with lower repair costs.

Nonintervention type activity

A nonintervention type activity in a PM manner is everything that is done to monitor the health of equipment and assets(Deighton 2016). The collection of the asset health information is often done on a routine maintenance round using checklists. When maintenance round like this is done either a skilled craftsman or a maintenance engineer look at the assets and note down the state of the equipment. The values of the parameters they note down are obtained by inspection, testing, and instrument values. If this is done regularly and the parameters are logged and stored correctly, it is possible to establish a baseline for normal operating conditions. It is easier to discover and gain awareness of degrading and failing equipment with a baseline or a norm. A nonintervention type of activity is also often used when regulatory inspections of critical equipment like, for example, hoists, straps, and relief valves are inspected.

Intervention type activity

In an intervention type of activity, the maintenance is done on a predetermined schedule. The maintenance done could be repair, replacement of essential components, or extensive servicing of the equipment(Deighton 2016). Often activities like this require shutdown of the operation and will add to maintenance cost. There is a point of optimal use of this type of activity where the cost of repair and cost of prevention intersect. This is often the two parameters maintenance managers try to balance to obtain the most cost-effective maintenance routine. The schedule is determined based on known statistics of the degradation of the equipment. From this, we can get a mean-time-to-failure (MTTF) which is represented by the bathtub illustration in figure 3.3 below. As can be seen, there is a high failure rate at the start of an asset or component's lifetime; then it settles before degradation sets on and the failure rate increases. The MTTF represents the mean time before the first failure occurs (Kollmorgen n.d.).

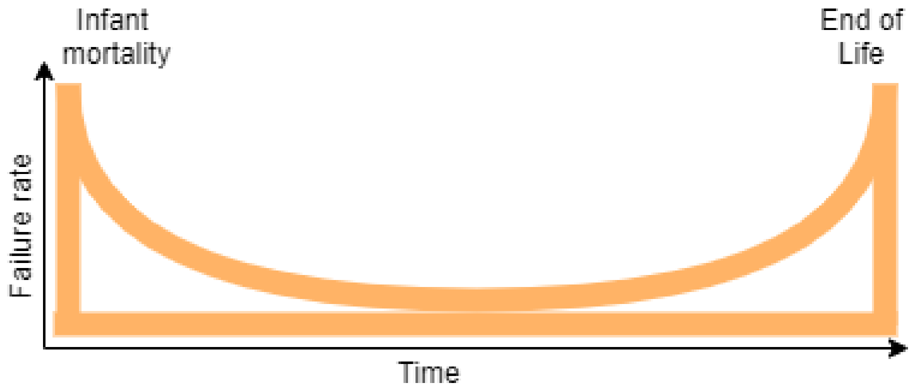


Figure 3.3: Mean-time-to-failure, [made by author]

Another metric often used when making a maintenance schedule is the mean-time-between-failures (MTBF). This is also based on statistical knowledge of the assets failure rate and will often be used as the main metric for determining necessary downtime for component replacement. An example of this could be if the main bearing of an engine has an MTBF of 1 billion cycles. If this is an engine in continuous use and with a steady speed of 1000 RPM, the MTBF would be abound 1.9 years. A planned replacement of the bearing could then be scheduled at the 1.8-year mark. Since the main bearing is not the only consumable part in an engine, it could be scheduled for replacement long before other components need to be changed. This is to avoid unnecessary downtime of the equipment. This is the main dilemma a maintenance manager is up against when choosing between corrective or preventive maintenance. On one hand, components are replaced long before it is broken, and on the other hand, components brake in use and could result in high repair cost.

3.1.3 Predictive maintenance

The problem stated at the end of section 3.1.2, "balancing when to decommission a component or asset due to its health," is the core objective of implementing and using predictive maintenance (PdM). A predictive maintenance model attempts to foresee when a component is about to fail utilizing sensors, and sophisticated software (Qureshi 2020).When PdM is working as intended it would give the maintenance managers a fuller picture of the state and health of the asset, that will in turn give them the ability to balance the prevention costs and repair costs as shown in figure 3.2. In figure 3.4 below a standardized scenario of equipment degradation is shown. This figure shows the performance of the asset over time from perfect operating conditions to total failure. If a preventive maintenance strategy is used, the component would have to be replaced before arriving at point P. This would lead to waste in the form of not utilizing the entire lifespan of the component. On the other hand, if the component is run until failure, the repair cost would increase. This is one of the dilemmas the maintenance managers are facing that PdM could counteract. By the use of sensors, it is possible to detect early on when degradation sets in. Further, this data could be used to predict when the equipment will fail. If the predictive models are good enough, the components could be used long after they would have been replaced using preventive maintenance. It would also make it possible to avoid disastrous failures that would lead to high repair costs. Using figure 3.4 as a general guide, PdM would enable maintenance managers to keep components in operation until somewhere between "Early Sign of Failure 2" and "Audible Noise." This strategy avoids waste both in terms of high repair cost and unused lifetime of components, balancing both aspects, leaving us at the optimum point as shown in figure 3.2.

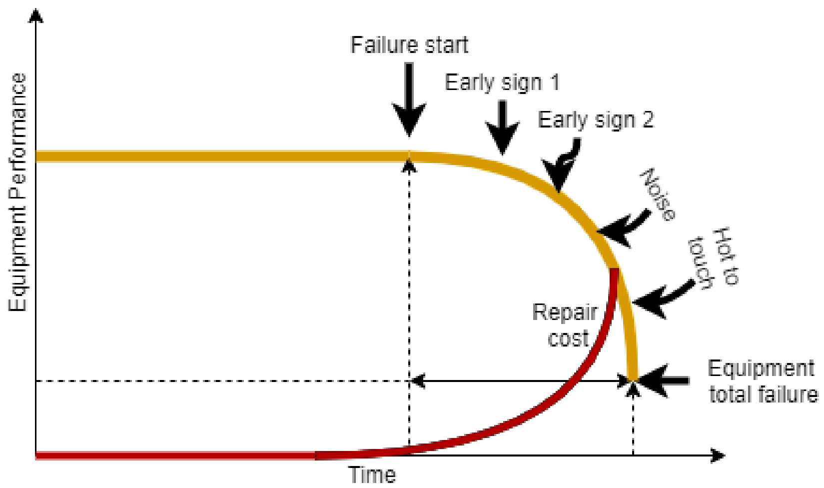


Figure 3.4: P-F curve failure of system, [made by author]

There are many methods for monitoring the asset in terms of how the data is collected, what failure mode is monitored, and how the data is analyzed after it is collected. This is what often is referred to as condition monitoring (CM). Below, a short description of the main data collection points is explained and a short description of how the data could be analyzed.

Vibration monitoring

Vibration monitoring is a technique that is often used for monitoring the health of rotating machinery and assets. Minor imperfections in surface finish, contact points between components, alignment, and balance are all contributors to the vibration that can be detected (Fedele 2011). If a component like, for example, a bearing wears out, this will generally result in a proportional increase in vibration that can be detected. This is also true if the bearing gets damaged, misaligned, or off-balance due to debris or damages.

For detecting the vibration of an asset, an accelerometer is attached to the asset where vibration from the component of interest can be detected. Often the acceleration is measured and stored for both X, Y, and Z directions(Deighton 2016). This gives the ability to graph the data and do a trend analysis that can predict the future health of the component. One of the strengths of using vibration as a predictive measure is that it often develops over time and becomes increasingly worse. With old historical data from the same type of asset, predictions could be made for a significant period of time into the future. An example of a failing bearing and the graphed vibration measurements are shown in figure 3.5 below. The trend might show seasonal, cyclical, or linear variations that can be used for further specification of exactly where the failure is coming from.

Figure 3.5: Failure of bearing over time, (Flovik 2019)

Another use of the vibration data is to set limits for the severity to know when to intervene with the operation and take measures for improvement. ISO 10816 shows a standard of how severe the vibration could be before actions should be taken (ISO 2009). Below in table 3.1, the vibration limits have been recreated and displayed based on the ISO standard.

Table 3.1: Severity of vibration, [made by author]

Machine		Class 1, Small Machines	Class 2, Medium Machines	Class 3, Large Rigid Foundation	Class 4, Large Soft Foundation
Vibration Velocity Vms	mm/s				
	0.28				
	0.45				
	0.71				
	1.12		Good		
	1.8				
	2.8		Satisfactory		
	4.5				
	7.1		Unsatisfactory		
	11.2				
	18		Unacceptable		
	28				
	45				

Oil condition monitoring

Oil is used for lubrication, reducing friction and wear of the asset by introducing a thin film between contacting surfaces. In equipment like, for example, a gearbox, the oil is circulated through so the components always are covered in it. This constant oil circulation makes it possible to use oil as a data point for condition monitoring. By investigating the amount of water and debris in the oil and the degradation of the oil itself, it makes it possible to assess the asset's health and trending the development for predictive purposes (Deighton 2016).

Several methods are used for assessing the health of the oil and the asset. As can be seen from figure 3.6 below, either a sample is collected and sent off for analysis in a laboratory, or sensors are connected to the oil stream either in parallel with the main stream or inline with the main stream.

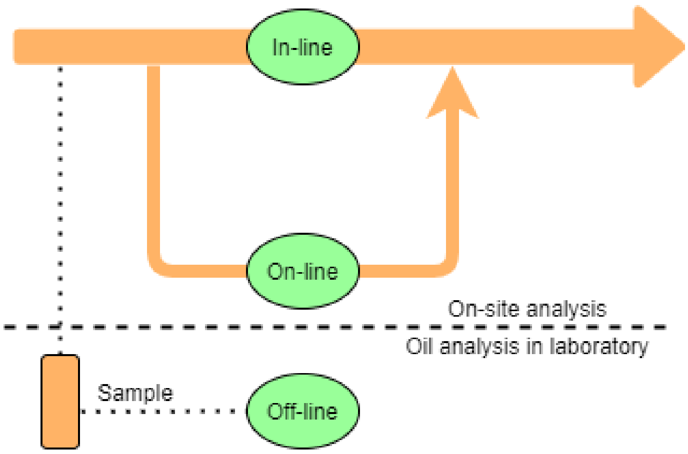


Figure 3.6: Methods of oil analysis, [made by author]

The obvious drawback of using the offline method is that it takes a long time for the results to come back, and the results might not be valid anymore. For both the online and inline methods, fixed sensor installations could be used. This will give a shorter lead time, and could in some cases provide the necessary data for real-time analysis. What can be detected and for what type of maintenance strategy they serve is listed below (Fedele 2011).

Proactive maintenance:

- Pollutant control
- Particle count
- Humidity
- Temperature
- Air in the lubricant mixture

Predictive maintenance:

- Viscosity
- Acidity
- Flammability
- Glycol levels

Data analysis

To utilize the collected data not only for condition monitoring in real-time but also to make predictions about the future state of the asset, the collected data have to be analyzed. Many methods exist for the analysis of time-series data. The most common methods when analyzing time series data for predictive maintenance are listed below. They are listed in ascending order with the simplest method first. All the analysis methods are described below each of the bullet points.

- Trend analysis

  Trend analysis is the most basic analysis method for time series data. However, it is effective and can make it possible to make predictions based upon historical data quickly, efficiently, and cost-effectively. A trend analysis is based on identifying the underlying components that make up a time series (Ullah 2014). This is shown in figure 3.7 below.

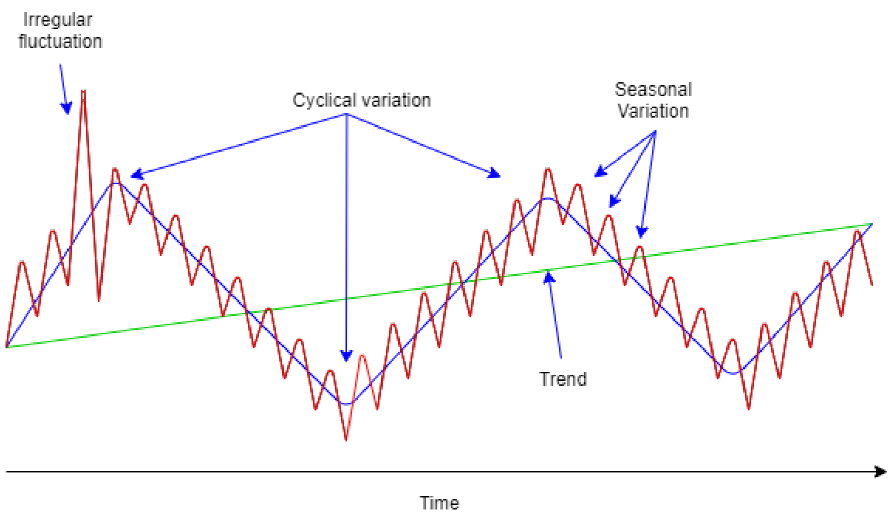


Figure 3.7: Timeline showing the components of time series data, [made by author]

As can be seen, in figure 3.7 above, time-series data can most often be analyzed by identifying the four main components that are: irregular fluctuations, cyclical variation, seasonal variation, and trend. The cyclical variation is when the values in the time series varies significantly over a more extended period of time in a reoccurring fashion. This can, for example, be the operational load of an asset due to the summer and winter demand of what the asset is used for. The seasonal variation is minor variations that follow the cyclical variation. This is also reoccurring, but in contrast to cyclical variation, the time span is shorter. Seasonal variation can, for example be temperature fluctuations over 24 hours. Irregular fluctuations are often something unexpected that happens without warning. As shown in the figure above, the trend is the values over the time period that has the same start and finish as the data set. A trend can also be fitted for smaller or larger sections of the time period.

- Statistical analysis

  Other more complicated methods than trend analysis are often used to predict the future state of an asset. This is to get a better understanding of the behavior of the data set and make more accurate predictions of the future state. Many methods are being utilized, but the most common one is regression. The purpose of regression is to describe the relationship between dependent and independent variables (Frost 2017). Said more easily, it is to fit a line in a plan between the X and Y axis closest to the data points in the plane. This is done by utilizing the formula closest to the data set you have ,for example, linear, quadratic, or cubic. The polynomials for the three regression types are shown in the list below.

$$Linear : ax + b = 0 \tag{3.1}$$

$$Quadratic : ax^2 + bx + c = 0 \tag{3.2}$$

$$Cubic : ax^3 + bx^2 + cx + d = 0 \tag{3.3}$$

  In figure 3.8 below, an example of linear, quadratic, and cubic regression is shown. In addition to these three types, many more can be utilized to analyze time-series data.

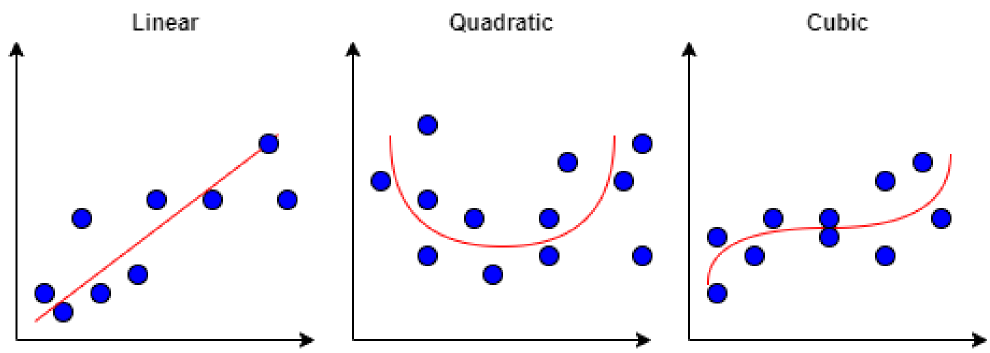


Figure 3.8: Graphic examples of linear, quadratic and cubic regression, [made by author]

- Artificial intelligence

  As data analysis methods become more and more complicated, so do the algorithms used to process the maintenance data. The trend within predictive maintenance is that artificial intelligence will take over more and more of the analysis. Artificial intelligence (AI) is explained more in-depth in section 3.2.

3.2 Industrial revolution 1 to 4

Several industrial revolutions in the newer era have massively impacted how we produce and transport goods and how we communicate and relay information. In figure 3.9 shown below, the rough timeline of the first, second, third, and fourth industrial revolution is displayed.

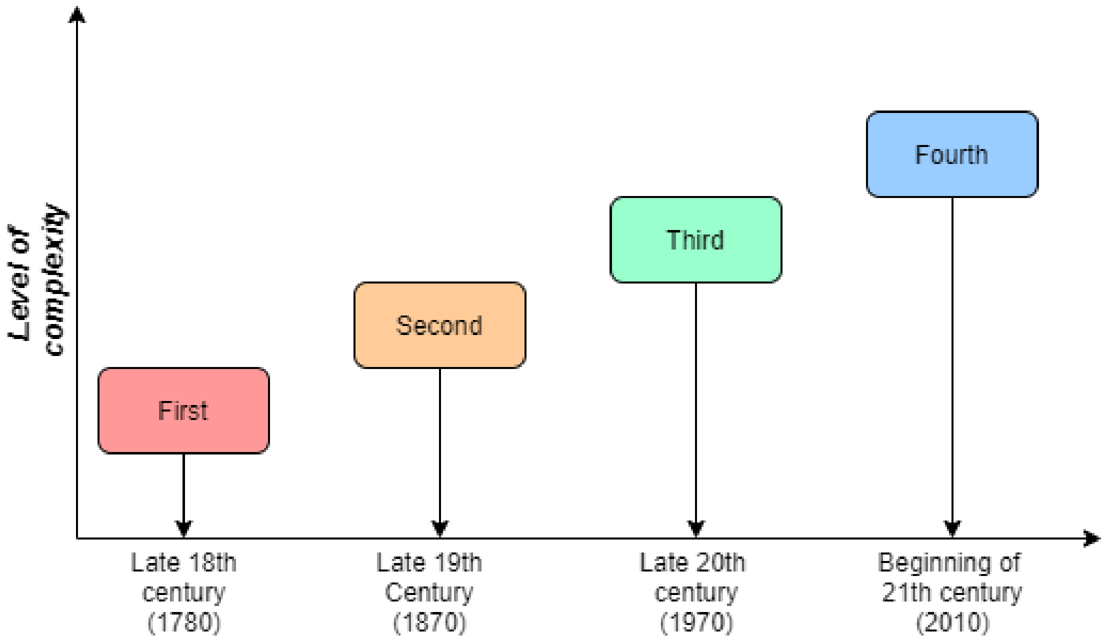


Figure 3.9: Industrial revolutions timeline, [made by author]

The first industrial revolution took place in the 18th century and is the starting point when human labor was replaced by machinery. The machinery replacing the human labor was, for the most part, driven by steam and water power (iED Team 2019). The new production methods made it possible to produce goods more effectively and cheaper. At the end of the first industrial revolution, the steam locomotive was also introduced, making transportation of the produced goods easier and more effective.

In the second industrial revolution, the power of oil, gas, and electricity was discovered. This made it possible to develop the combustion engine, electric lighting, motors, and other electrical devices for communication (iED Team 2019). The electrical motors in production facilities made it possible to mass-produce goods at a lower cost and more effective than ever before. The assembly line production was invented and made huge improvements.

During the third industrial revolution, telecommunication, electronics, nuclear power, and robots were introduced. The new inventions gave us the ability to program logic boards and computers (iED Team 2019), Hence giving us the ability to automate even more of the manufacturing processes(Marr 2018).

3.2.1 Industry 4.0

The fourth industrial revolution, often referred to as industry 4.0, is the one we are currently at the beginning of. The definition of this era is the rise of cyber-physical systems (Marr 2018). This means systems that are interconnected and can receive and send information through the use of a communication network. For example, robots in a production plant that work together and are all connected to a central operating system that can give them mission data they can act upon. There are many subbranches of industry 4.0, but the most impotent ones are described in the subsections below.

IoT

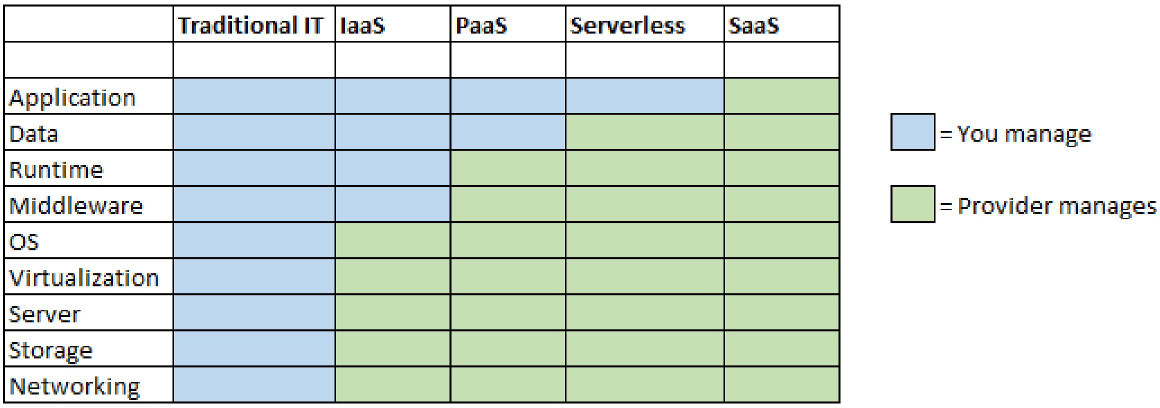
Internet of things, also called IoT, is the connection of devices (things) over the internet (Somayya Madakam 2015). The devices are often outfitted with sensors, transmitters, and receivers to accept and transmit data. Often, the devices have a built-in logic of themselves to make independent decisions based on the information they have access to. IoT devices include everything connected to the internet, all from small devices used at home to large industrial equipment. According to Statista.com (Vailshery 2021), the number of IoT devices in the world in 2018 was about 22 billion devices. They estimate that the amount of IoT devices will reach 50 billion by 2030. The prospects of the market potential are huge and will, by all likelihood, continue to grow. The abilities and opportunities give by IoT to the industry is enormous and lay the foundation for a paradigm shift in many industries.

The opportunity to build in sensors in assets for monitoring and connecting the assets to a more extensive network of other sensors and assets is, in some part, a real-world application of IoT with condition monitoring and predictive maintenance in mind. As the IoT technology advances, PdM and CM draw the benefit of this and advances as well. However, PdM is reliant on other factors as well, like cloud computing and artificial intelligence. These topics are explained below.

Cloud computing

Cloud computing is the use of computing services over the internet. This can, for example, be access to databases, storage, programs, or application (Jake Frankenfield 2020). Cloud computing is a way for small and medium businesses to get access to infrastructure and programs they otherwise would not have the financial strengths to do. The Cloud Computing industry is divided up into four main categories of service. The different services are shown in table 3.2 below, followed by a short explanation of all the services and who manages what (Sai Vennam 2020).

Table 3.2: Cloud computing services, [made by author]



- Infrastructure-as-a-Service (IaaS)

  Iaas is the least involving cloud computing systems. It covers a customer's need for everything from OS to servers but leaves the programs, applications, and data to the customer.

- Platform-as-a-Service (PaaS)

  The customer gets access to everything in a PaaS service, as shown in the table 3.2 above, except data and applications.

- Serverless computing

  Serverless computing is an almost all providing solution, except the application. The application used can be from a third party or an internally developed application.

- Software-as-a-Service (SaaS)

  As the name suggests, SaaS is a software service that includes everything a customer needs to use the software over the internet. As can be seen from figure 3.2, the SaaS is the service that manages most of the customer's needs out of all the systems.

Artificial intelligence

Artificial intelligence (AI) is a general description of algorithms of various sorts that can process data based on different inputs. There are many definitions of AI, but according to Store Norske Leksikon, (Tidemann 2020) one definition is when a computer can solve tasks without the interaction of humans. AI is a collective concept consisting of sub-concept. Their relationships are illustrated in figure 3.10 below. Below the figure, a brief description of every sub-concept is described.

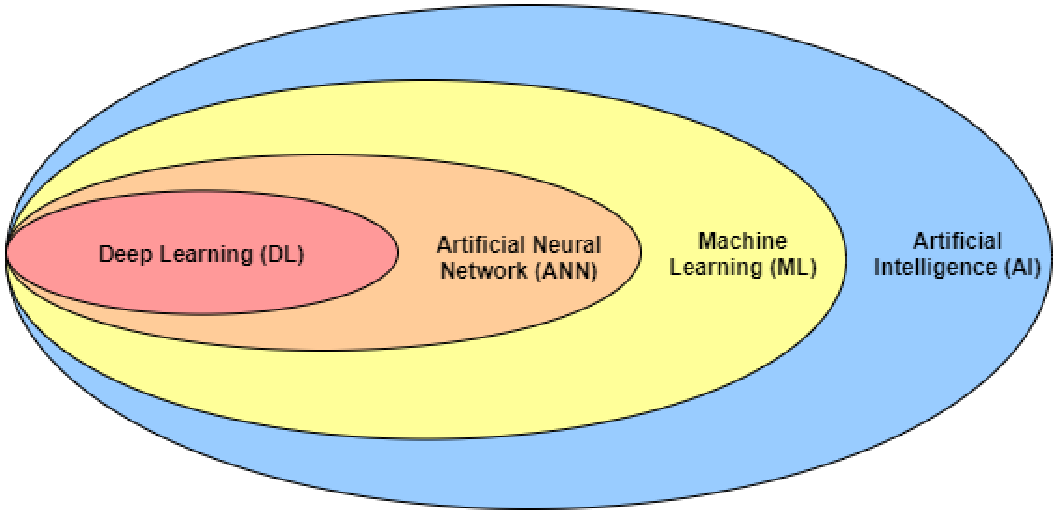


Figure 3.10: AI, ML, ANN, DL, [made by author]

- Artificial Intelligence

  As explained above, AI is the largest definition that all the other methods of artificial intelligence computing are built upon. It is the earliest form and consists of simple algorithms that have built-in logic to them. Since the algorithms are at a certain size and can make decisions based on the input and restrictions in the algorithm, it is considered AI. The first research and development of AI started as long back as in 1960 (Anyoha 2017).

- Machine Learning

  Machine learning is the further development of AI that consists of more than just simple algorithms. It is a statistical tool that automatically learns and further develops based on the information the algorithm has available (Expert.ai Team 2020). There are three main subsets of categories in machine learning that build on three different types of algorithms. These methods are briefly explained in the list below (Expert.ai Team 2020) (IBM Cloud Education 2020).

  – Supervised ML

    The algorithm is trained on historical data introduced by a data scientist. The model then can make predictions of the future state based on the previous data. The use case is to predict patterns and extrapolate them into the future.

  – Unsupervised ML

    For unsupervised ML, the algorithm is not trained on historical data, but it is searching for trends and patterns within the available data. This algorithm's use case identifies statistical patterns within the available data and clusters the data points.

– Reinforcement ML

Reinforcement machine learning is when the algorithm is an agent exploring an environment without "rules" that the agent has to follow. The agent learns by receiving predetermined rewards and punishments in its environment and finding a pattern that maximizes the rewards.

- Artificial Neural Network

  An artificial neural network is based on the idea that algorithms can simulate how the human brain works. It is based on an input layer, one or more hidden layers, and an output layer (IBM Cloud Education 2020). This is shown in figure 3.11 below. The input layer consists of units of information. This information is then transferred to the hidden layers, where it gets assigned a weight of importance. Based on how valued the network thinks the information is, it will either stop or get sent to the output layer. The units in the output layer will then get assigned a value, and the unit with the highest value will be considered the suitable unit. As the neural network needs to be trained to work, both the input layers and output layers are controlled at the start. This gives the network feedback to correct itself and give the right answers with a higher probability (Larry Hardesty 2017). An example of a use case of ANN is facial recognition, the direct translation of a text, and computer vision.

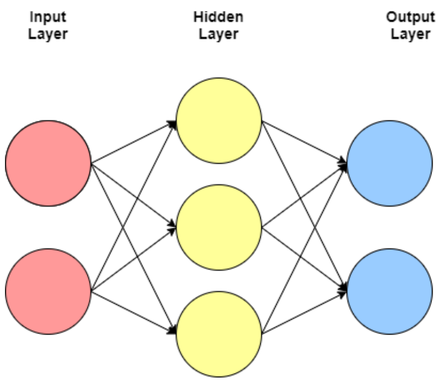


Figure 3.11: Artificial Neural Network, [made by author]

- Deep Learning

  Deep learning is essentially the same as an artificial neural network. The difference is that deep learning consist of more than three layers, whereas an ANN only consists of three. A deep neural network normally works in one direction, meaning from input to output. This is called propagation. However, it can also be learned through back-propagation, much like in a three-layer neural network(Eda Kavlakoglu 2020). The added benefit of a deep neural networks is that with more hidden layers, the model can take into account more parameters and become even more accurate.

3.3 Analysis theory

When processing the collected data in this thesis, several analysis methods have been used. They are all listed below in their own subsections with an explanation about the theory surrounding each of the methods.

3.3.1 Needs and Requirement

A needs and requirements analysis is a method used to get an overview of the needs of an individual, groups of people, or organizations. In the case of this thesis, a stakeholder needs and requirement analysis is conducted. The funding principle of a needs and requirement analysis is to figure out "what" your stakeholders want to have built, not "how" they want something built (Alan Faisandier, Garry Roedler 2021). There are many way of conducting a needs and requirement analysis, but the way it is done in this thesis is shown in table 3.3 below.

Table 3.3: Needs and Requirements example, [made by author]

Stakeholders	Needs	Requirements	Criteria
Stakeholder 1 (SH1)	Needs for SH1	Req for SH1	Crit to accomplish Req for SH1
Stakeholder 2 (SH2)	Needs for SH2	Req for SH2	Crit to accomplish Req for SH2
Stakeholder 3 (SH3)	Needs for SH3	Req for SH3	Crit to accomplish Req for SH3
Stakeholder 4 (SH4)	Needs for SH4	Req for SH4	Crit to accomplish Req for SH4

The first task is to identify the stakeholders that are involved, and that should be a part of the analysis. This can be done by looking at the company or the system that focuses on analyzing and drawing out what stakeholders are either affected or can affect the system (Jason Fernando 2021). When this is done, all the needs from each stakeholder have to be collected. This is typically done through either interviews or questionnaires. When the needs have been collected, the requirements to accomplish the needs are written down, followed by the criteria needed to accomplish the requirements.

3.3.2 Systems of systems (SOS)

A systems of systems analysis is a constellation of several systems that works together to create a larger system (Pierre Dersin, Alstom Transport 2014). It is an often used method in systems engineering for gaining an overview of how the systems and subsystems are connected in relation to each other. There are many ways of illustrating an SOS, but the way it is shown in figure 3.12 below follows a path of subsystems leaving the user of the SOS with the end product or task level of the final subsystem. The version of SOS used in this thesis is divided into industry level, enterprise-level, department level, responsibility level, and task level.

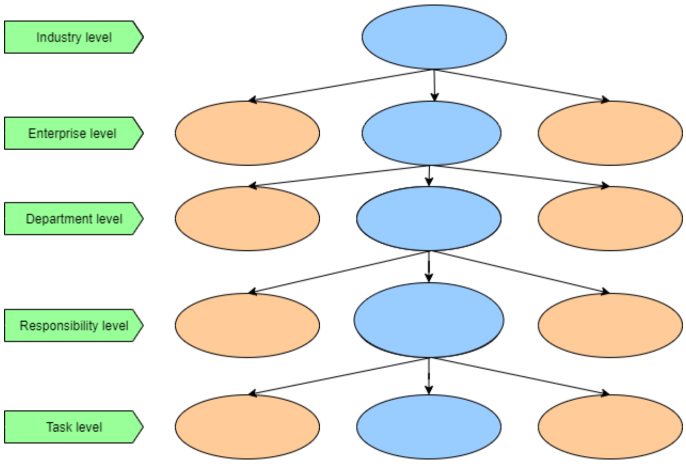


Figure 3.12: Example illustration of SOS, [made by author]

3.3.3 Maturity

The purpose of a maturity analysis is to pinpoint how far a company or an organization has come in the implementation of specific processes. In this thesis, the process or system of interest is the maturity level in regards to predictive maintenance. A maturity analysis can also show how good a company or organization is at self-improvement (Adam Henshall 2019). The first maturity model that was developed was in 1979 and is called Crosby's Grid. This was then followed by CMM in 1987, Bessant's Model in 1997, CMMI in 2000 and OMG in 2002 (Albliwi et al. 2014). All of these models have different targets and criteria that makes them useful in each of their own domain. This is shown in table 3.4 below.

Table 3.4: Comparison of maturity models, [made by author]

Criteria	Corby`s Grid	Bessant`s Model	CMM	CMMI	OMG
Target	Quality Management	Continous Improvement	Software Industry	Different Industries	Business Process
User-friendliness	Yes	Yes	No	No	No
Training	No	No	Yes	Yes	Yes
Prior knowledge and experience	Yes	Yes	Yes	Yes	Yes
Clearity of determining the current level of maturity	Yes	Yes	Yes	Yes	Yes
Empirical evidence	No	Yes	No	Yes	No
Theoretical based	No	No	No	No	No
Researcher experience based	Yes	Yes	No	No	No
Quality standards/previous model based	No	No	Yes	Yes	Yes
Complexity	No	No	Yes	Yes	Yes
Performance based scoring system	No	No	No	No	No
Accuracy	No	No	Yes	Yes	NA
Availability of criteria to determine the current stage of maturity, when the stage is completed and when to move to the next stage	No	No	No	No	Yes
Validity/ reliability/ generalization	No	No	No	No	NA

The maturity analysis model closest to the analysis model used in this thesis is Crosby's

Grid. The model design here is based upon a grid so that the maturity can be assessed in both the horizontal and vertical direction. The basis for the analysis framework and model used in the thesis is the maturity model made by PWC and Mainnovation (Michel Mulders 2018). This model and framework is shown in figure 3.13 below.

Capability	1. Visual Inspection	2. Instrument Inspection	3. Real Time Condition Monitoring	4. PdM 4.0
Processes	- Periodic inspection (Physical) - Checklist - Paper record	- Periodic inspection (physical) - Instruments - Digital recording	- Continuous inspection (remote) - Sensors - Digital recording	- Continuous inspection (remote) - Sensors and other data - Digital recording
Content	- Paper based condition data - Multiple inspection points	- Digital condition data - Single inspection point	- Digital condition data - Multiple inspection points	- Digital condition data - Multiple inspection points - Digital environment data - Digital maintenance history
Performance Measurement	- Visual norm verification - Paper based trend analysis - Prediction by expert opinion	- Automatic norm verification - Digital trend analysis - Prediction by expert opinion	- Automatic norm verification - Digital trend analysis - Monitoring by CM software	- Automatic norm verification - Digital trend analysis - Prediction by statistical software - Advanced decision support
IT	- MS Excel/MS Access	- Embedded instrument software	- Condition monitoring software - Condition database	- Condition monitoring software - Big data platform - Wifi network - Statistical software
Organisation	- Experienced craftsmen	- Trained inspectors	- Reliability engineers	- Reliability engineers - Data scientists

Figure 3.13: Level of PdM maturity, [made by author, based on PWC's maturity framework (Michel Mulders 2018)]

3.3.4 Gap

A gap analysis aims to identify the missing capabilities of an organization or a system and facilitate improvement. According to Investopedia (Will Kenton 2020), there is a four step process that can be followed to conduct the analysis. The four steps are shown in figure 3.14 below.

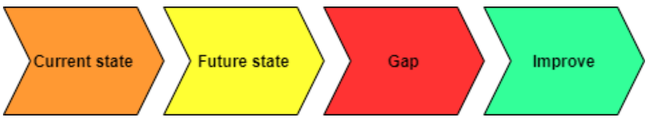


Figure 3.14: Gap analysis procedure, [made by author]

Step number one is to understand the current situation. This has been achieved in this thesis by performing a maturity analysis. This step serves as a benchmark. The next step is then to construct and understand the goals of the organization or the company. This is achieved by performing a needs and requirement analysis. The third step is then to identify the missing features and capabilities between the current and future state. This is what is called a gap. The fourth and final step is to suggest improvements and report how the identified gaps can be closed.

3.3.5 SWOT

The purpose of the SWOT analysis is to give a framework so a company can be assessed for its strengths, weaknesses, threats, and opportunities. The SWOT analysis is an analysis method that gives an overview of external and internal factors that affect a company and gives an overview of the present and future state; (Will Kenton 2021). Below in figure 3.15 an example of how a SWOT analysis is set up is shown. Below the figure, a list of questions one can ask to fill out the table is shown. The questions are example questions gotten from investopedia.com (Will Kenton 2021). These questions are only examples and can be changed, taken away, or other new questions can be added.

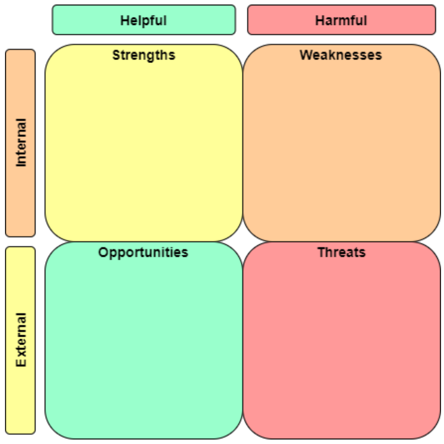


Figure 3.15: SWOT Example, [made by author]

- Strengths

  1. What competitive advantage does the company have? 2. What resources do the company have access to? 3. What products or services are the company doing well at the moment?

- Weaknesses

  1. What can be improved in the company? 2. What products or services are not performing well? 3. What resources do the company not have access to?

- Opportunities

  1. What new or existing technology can be used to improve current and future operations? 2. Is there any room for expanding services? 3. Is there any new market segments that can be explored?

- Threats

  1. Any regulatory restrictions that can come in the way of the operations? 2. Will our customers outperform us? 3. Is there any trends that might threaten the business model we have today? ,

Chapter 4

Data Collection

In this chapter, a clarification of what, how, and who collected all the necessary data needed to conduct the analysis is shown. The chapter is divided into the sections Research in the Høglund cloud system, questionnaire, semi-structured interviews, and reliability data. All the sections are made up of subsections that go into depth about the "what," "who," and "how" of each of them.

4.1 Research in the Høglund cloud system

To better understand the cloud service system that Høglund is currently offering their customer, the author explored and researched the programs and functionalities within the cloud service system. To provide the reader with an overview of the cloud service system, it has been illustrated in figure 4.1 below.

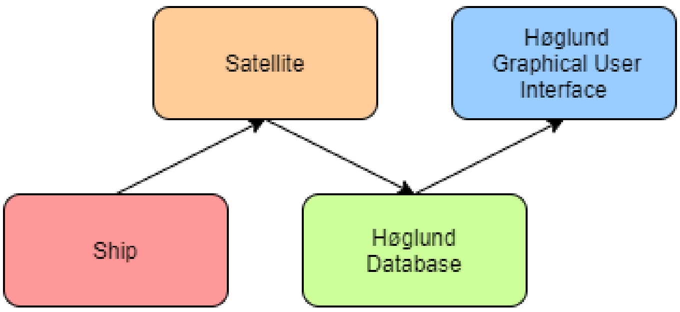


Figure 4.1: Høglund's Cloud Service System Overview, [made by author]

The system works, as shown in the figure above. The assets onboard the ships, e.g., the main engine, are outfitted with sensors. The sensors that Høglund mainly uses are temperature and pressure. The sensor values are then uploaded to the Høglund database once every minute by the use of satellite. All data is then saved in the database, where it can be extracted for later use. The database that Høglund is currently using is a third-party server called "MongoDB." "MongoDB" is classified as a NoSQL program that also uses JSON documents. The data in the database can then be extracted and shown to the systems users either by using Excel as an "Application Program Interface" called API for short or Høglund's own GUI, which is called Fleet Manager.

Høglund has many systems within their portfolio of systems that can be accessed through the cloud service using their API and GUI. Not all of the systems are relevant for this thesis and are therefore not discussed. A complete overview of the systems Høglund is offering can be seen in chapter 1 in figure 1.3. The relevant system with PdM in mind is the "Ship Performance Monitor" (SPM). A screenshot of the SPM system in Fleet Manager is shown in figure 4.2. With the SPM system, it is possible to get a live view of the main engine and other assets on board. For delimiting purposes, only the main engine is used as the asset of interest. To access historical collected data that can be extracted and used for analysis, it is necessary to use the Excel API and download the needed data.

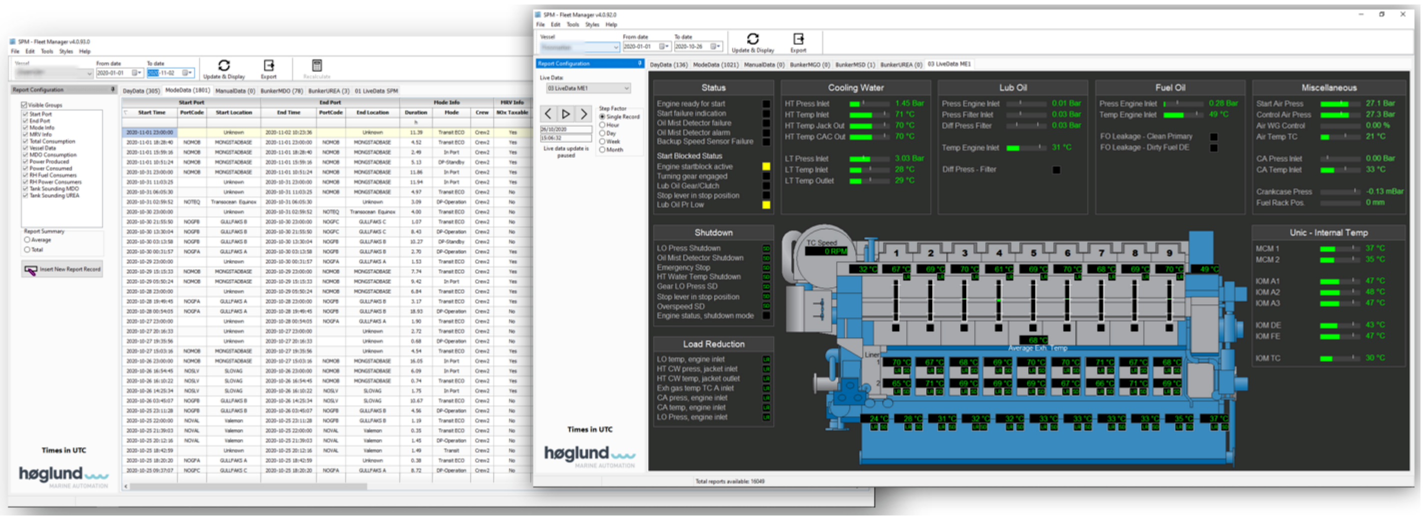


Figure 4.2: Example view Fleet Manager, (Solutions n.d.)

4.2 Semi-structured interviews

Since the mission of this thesis was not 100% decided in January, the first part of the research was done using semi-structured interviews. Mostly this was done to understand the problems that Høglund was facing, the abilities they had at the moment, and their goals. Interviews were also conducted with the customers of Høglund, classification companies, and other potential customers. Because most of the interviews were done over the phone and with varying knowledge of the task at hand, it was not fully documented. However, some notes were taken from each of the interviews containing the discussed topics, who was giving the interview, and roughly when the interview found place. As there have been several phone calls with many of the participants in the semi-structured interviews, some of them are given a time period instead of an exact time. In table 4.1

below, an overview of the interviews is shown, containing the time period of when it took place, who is interviewed, their position and company, and the discussed topics.

Table 4.1: Semi structured interviews overview, [made by author]

When:	Who:	Position:	Company	Topic of discussion:
Oct. 2020 --> end of thesis	Aleksander Beckmann	Sales Manager - Digital Solutions	Høglund	• Needs and requirements • Current state of the Høglund system • Goals of future evolvement of the system • Access to data and systems • Research question
Oct. 2020	Didrik Høglund	Sales manager	Høglund	• Needs amd requirements for Høglund • Limitations • Research question
Nov. 2020 --> Feb.2021	Daniel Lorentzen	Automation Service Engineer	Høglund	• Technical aspects of the Høglund cloud service cystem
Jan. 2021 --> Mar. 2021	Sven Rolfsen	Technical Manager	Utkilen	• Current state of Utkilen`s ships • Previous breakdowns in the ships internal assets (e.g main engine, fuel pump etc) • Maintenance regime
Mar. 2021 & May. 2021	Ivar Brekke	Technical section leader (Chief engineer)	Dolphin Drilling	• Current state of Dolphin drillings Platforms • Maintenance regime • Current use of sensors and analysis
Mar. 2021	Pål Kenneth Røsand	Principal Engineer	DNV GL	• Classification of ships and platforms in regards to PdM

4.3 Questionnaire

To conduct the maturity analysis, followed by the gap and SWOT analysis, many questions need to be answered. A questionnaire was made and sent out to Høglund, Utkilen, and Dolphin Drilling to ensure consistent questions. Because a lot of the information about Høglund was already collected through the semi-structured interviews and research in the Høglund cloud system, Høglund answered a shorter version of the questionnaire. Most of the questionnaire is based on the framework made of PWC (Michel Mulders 2018), and is made to answer the scorecard used in the maturity analysis. Some additional questions are inspired from the work done in Alexander Carlsen‘s thesis (Carlsen 2020). Below, the questionnaire is shown in full (32 questions) with explanations to every section of it. The answers to the questionnaires are attached in the appendix.

4.3.1 Part 1: Background information

The background information is collected to understand who is answering the questionnaire, their position, and what company they are representing. It is also reviling the current state of their maintenance operation and their current use of Høglund‘s system, and their motivation for implementing PdM in their operation. Below are all the questions and possible answers to part 1.

- Question 1: Your name?

  ☐ Text answer: ....

- Question 2: Your position?

  ☐ Text answer: ....

- Question 3: Company name?

  ☐ Text answer: ....

- Question 4: How is maintenance done today for your assets?

  ☐ Corrective/ Reactive
  ☐ Preventive
  ☐ Predictive

- Question 5: What is the strongest motivator for implementing predictive maintenance?

  ☐ Increased uptime
  ☐ Increased lifespan of asset
  ☐ Reduction of operation cost
  ☐ Classification
  ☐ I do not think it is useful
  ☐ Other: Text answer: ....

- Question 6: What is the most important aspect of the cloud service system that Høglund provides today for you?

  ☐ Text answer: ....

4.3.2 Part 2: Process

Part 2 is the first section that contains questions that directly correspond to the criteria in the scorecard in the maturity analysis. The process section is there to understand how the maintenance data is collected. The questions from part 2 are shown below.

- Question 7: Are the assets inspections periodic or continuous? (Assets could, for example, be the main engine, diesel generator, etc.)

  ☐ Periodic
  ☐ Continuous

- Question 8: Are the inspections done remotely or in-person by an operator?

  ☐ Remote inspections
  ☐ In person inspections
  ☐ Both

- Question 9: How much of your data is collected using sensors?

  ☐ $\leq 20\% - -None$
  ☐ $\geq 20\% - -Few$
  ☐ $\geq 40\% - -Some$
  ☐ $\geq 60\% - -Most$
  ☐ $\geq 80\% - -Almostall$
  ☐ $= 100\% - -All$

- Question 10: Is the inspection done using a checklist?

  ☐ Yes
  ☐ No

- Question 11: Is the maintenance recorded analog or digital?

  ☐ Analog
  ☐ Digital

4.3.3 Part 3: Content

This section mainly consists of questions that are aimed at answering the scorecard in the maturity analysis. For clarification purposes, question 13 is an additional question that is not found in the scorecard. The purpose of the content section is to clarify what data is collected. The questions regarding this section are shown below.

- Question 12: Is the condition data recorded digitally or on paper?
  ☐ Digital
  ☐ Paper
  ☐ Both
- Question 13: If condition data is collected, what sort of sensors are installed on your asset?

  ☐ Temperature
  ☐ Pressure
  ☐ Oil debris
  ☐ Vibration
  ☐ Acoustics
  ☐ Other

- Question 14: Is the condition data recorded by a single or multiple inspection points?

  ☐ Single
  ☐ Multiple
- Question 15: Is environmental condition data collected and stored digitally?

  ☐ Yes
  ☐ No
- Question 16: Is historical maintenance data collected and stored digitally?

  ☐ Yes
  ☐ No

4.3.4 Part 4: Performance measurement

In part 4, all the questions are engineered to answer the criteria in the scorecard. The performance measurement is there to answer how the collected data is used and analyzed. Below all the questions from part 4 are shown.

- Question 17: Is there a visual norm verification in regards to the asset?

  ☐ Yes
  ☐ No
- Question 18: Is the norm verification automatic?

  ☐ Yes
  ☐ No
- Question 19: Is the trend analysis done digitally or on paper?

☐ Digitally
☐ Paper
☐ Both

- Question 20: Does the data points get monitored by condition monitoring software?

  ☐ Yes
  ☐ No

- Question 21: Are predictions of the future state of the asset done by experts or by the use of statistical software?

  ☐ Experts
  ☐ Statistical software
  ☐ Both

4.3.5 Part 5: IT

Part 5 also mainly contains questing that correspond to the criteria in the scorecard. In addition, it contains some questions that are aimed at gaining a broader understanding of the IT system that is in place. This is questions 26, 27, 29, and 30. The primary purpose of the IT section is to understand what IT infrastructure that is in place. The question from this section is shown below.

- Question 22: Which information and communication platform/software (ICT) is used by your company? (e.g., ERP, CMMS, SACA, etc.)

  ☐ Text answer: ....

- Question 23: Is condition monitoring data automatically stored?

  ☐ Yes
  ☐ No

- Question 24: If yes on question 23; Where is condition monitoring data stored?

  ☐ Text answer: ....

- Question 25: Is condition monitoring data classified and stored accordingly?

  ☐ Yes
  ☐ No

- Question 26: If yes on question 25, what classification requirements are used to organize the data?

☐ Asset tag number
☐ Time
☐ Data format (e.g vibration, temperature, pressure etc)
☐ Date
☐ Other

- Question 27: If you have multiple ICT systems; Are they connected and "talk" to each other?

  ☐ Yes
  ☐ No

- Question 28: How is the data transmitted? (e.g., Wifi, fiber optics, satellite)

  ☐ Text answer: ....

- Question 29: Who receive the data?

  ☐ Internal system on operation side
  ☐ Internal system onshore
  ☐ External third part receives the data

- Question 30: If third part receive condition data; Specify who they are and what they do with the data

  ☐ Text answer: ....

4.3.6 Part 6: Organization

The last part of the questionnaire is part 6, containing the Organization. This mainly shows what personnel are available. In addition, question 31 is added to get a better understanding of the company culture. The questions from section 6 are shown below.

- Question 31: Is there a willingness internally for implementing predictive maintenance for your assets?

  ☐ Yes
  ☐ No
  ☐ Other answer: Text answer ......

- Question 32: What of the following personnel do you have access to internally for maintenance analytic?

  ☐ Experienced craftsmen
  ☐ Trained inspectors
  ☐ Reliability engineers
  ☐ Data scientists
  ☐ Other answer: Text answer ......

4.4 Reliability data

To make suggestions on improvements after the maturity and gap analysis is conducted, reliability data of the assets that are assessed is needed. In this thesis, the diesel engine is used as an example asset. This is because it is a crucial part of the operation both for Utkilen and Dolphin Drilling. At Utkilen, the main engine is there to provide propulsion as well as generate electricity. At Dolphin Drilling, they also use big diesel engines, but only to generate electricity.

To provide improvement suggestions and support Høglund with data-driven decisions regarding PdM, the Offshore Reliability Data Handbook - also called OREDA (SINTEF 2002) was first thought of as the best resource for general reliability data on diesel engines. An initial trial was done to extract the reliability data of the most critical components in the diesel engine from OREDA and make a Pareto chart from it. However, OREDA does not contain many of the rotating elements that a diesel engine is made up of. For example, main bearings and big end bearing. Since the most proven and reliable predictive maintenance methods are vibration and oil analysis, the components mentioned in OREDA were not sufficient.

To get the necessary reliability data of diesel engines containing main bearings as a component, external sources were utilized. A research paper from Pennsylvania State University is used as the background for the reliability data. The paper has collected maintenance records from numerous diesel engines and prepared the numbers for the analysis (Steve Nixon 2018). A pareto chart of the failure modes VS the downtime for the maintainable items that makes up a diesel engine is shown in figure 4.3 below.

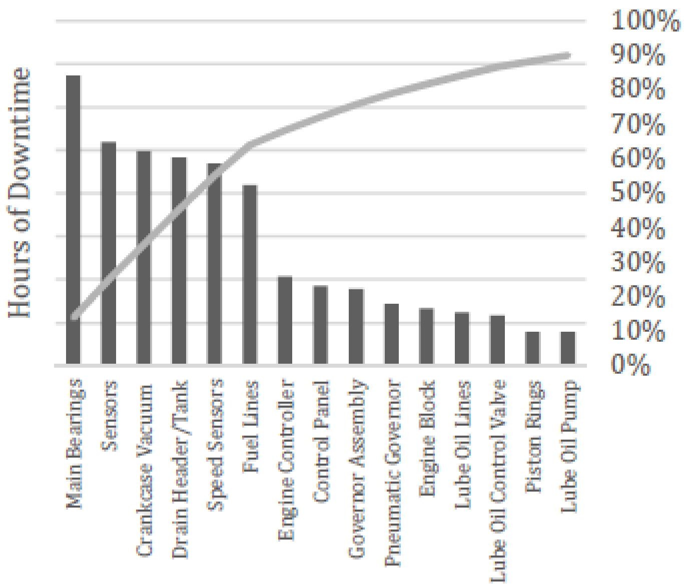


Figure 4.3: Maintainable items VS Downtime, (Steve Nixon 2018)

Chapter 5

Analysis and Results

The analysis consists of multiple sections building upon each other. First, a systems of systems diagram showing Høglund and their customer Utkilen is displayed, followed by a needs and requirements table. Then a maturity analysis of both Høglund and Utkilen is conducted based on the maturity survey and the framework made by PWC(Michel Mulders 2018). For additional insight, a similar company to Utkilen (Dolphin drilling) that could be a potential future customer of Høglund is also included in the maturity analysis. Further, when both Høglund, Utkilen, and Dolphin drilling has been placed on a maturity level, a gap analysis is conducted. This is done to answer the research question on how Høglund could reach a level of PdM4.0. This section assesses what needs to be done in terms of both hardware and equipment improvements and software. Last, a SWOT analysis of Høglund is conducted holistically to gain an overview of weaknesses, strengths, threats, and opportunities that Høglund is up against in their transformation towards PdM4.0.

The last three steps in the analysis section affect each other and could therefore be pictured as a loop, whereas the two first steps stay constant. This is illustrated in figure 5.1 below.

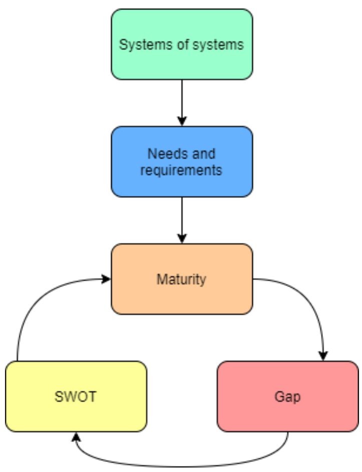


Figure 5.1: Process chart of the 5 analysis steps, [made by author]

5.1 System of systems

As can be seen in figure 5.2 below, a systems of systems diagram is showing the end state as if Høglund comes through and matures to a level 4.0. It is divided up into two paths that show both Høglund on the left and their customer Utkilen on the right. As can be seen from the diagram, both companies are a part of the same industry but are in different sections at the enterprise level. On the left side, we see Høglund's department level is IT. If this track is followed down to the task level, we see that Høglund can do the data collection and analysis. On the right side, we see that Utkilen's task level is execution, reporting, and maintenance programs. At the task level, we see what Høglund could offer their customers if they were fully mature.

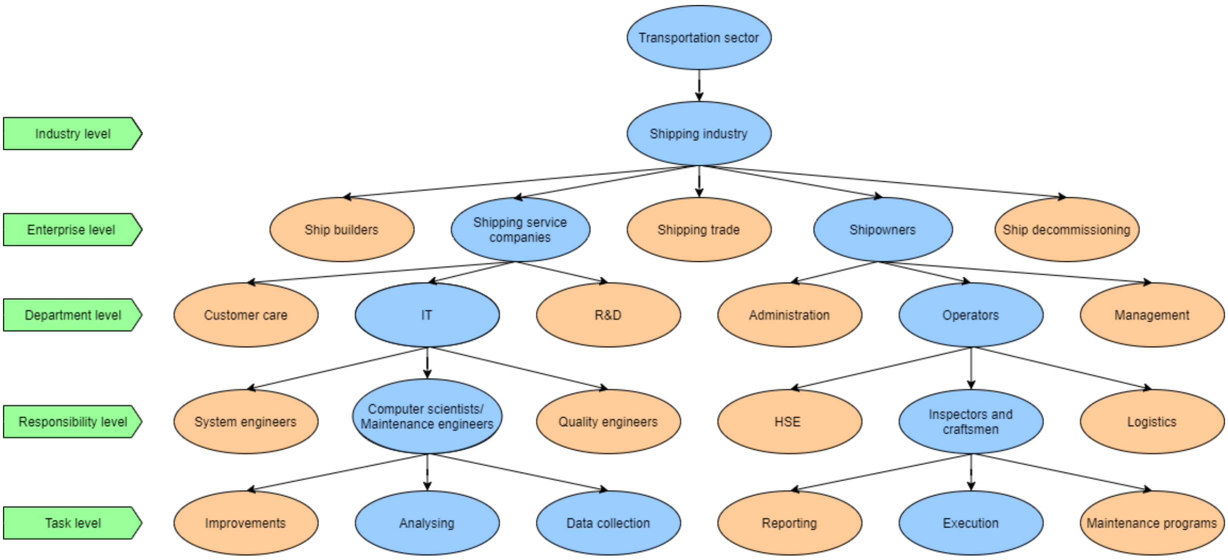


Figure 5.2: SOS diagram representing Høglund and Utkilen, [made by author]

5.2 Needs and requirements

Below in table 5.1, a needs and requirements table for the main stakeholders is displayed. The needs and requirements table is conducted with the cloud service system and PdM in mind. As can be seen from the table, the main stakeholders are the service company that delivers a system like this, the customer of the system, the government, and the classification company. The class company is a stakeholder because they are the ones classifying the assets (ships). The classification affects the maintenance and inspections that are compulsory, as well as the insurance.

Table 5.1: Needs and requirements, [made by author]

Stakeholders	Needs	Requirements	Criteria
Service company (Høglund)	* A close collaboration with their customers. * Information about the asset's functionality, limits, parameters, reliability, and maintenance requirements.	* Asset technical specifications * Data points * Analysis tools * Historical data	* Communication * Financial margins * Measurable * Reliable data
Customer (Utkilen)	* Close collaboration with their service company, class company, and government. * A safe and efficient operation with as little as possible downtime, maintenance, and operation costs.	* Asset condition * Procedures * Guidelines and standards * Reliable analytics	* Cost-effective * Reliable data * A good ITC system * Communication * Routines
Classification company (DNV GL)	* Close collaboration with the customer. *Information about the asset regarding the safety, maintenance, and operations parameters.	* Maintenance records * Asset technical specifications * Inspections	* Reliable data * Communication * Maintenance program knowledge
Government	* Close collaboration with class company and customer. * Information about the asset regarding maintenance, safety, and environmental impact.	* Risk mitigation * Financial records * HQSE procedures * Environmental procedures	* Transparency * Communication

5.3 Maturity analysis

The maturity is conducted for Høglund concerning their cloud service, one of their customers: Utkilen, and another company that could be a future customer of Høglund. The purpose of the maturity analysis is to benchmark how mature the companies are regarding PdM readiness and what they lack to get to a top-level. Figure 5.3 below shows the relationship between Høglund, Utkilen, and Dolphin drilling. To answer the research question, it is essential to assess the maturity of both Høglund and its customers because both need to be at a high level of maturity for PdM to be implemented.

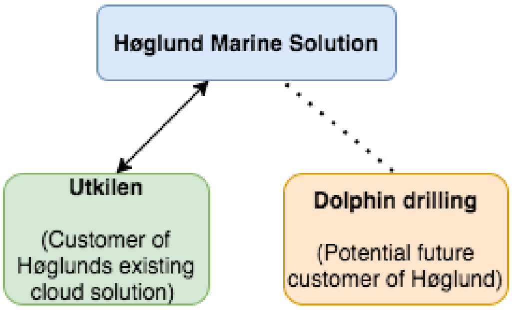


Figure 5.3: Relationship between Høglund, Utkilen and Dolphin drilling, [made by author]

5.3.1 Framework

To assess the maturity and benchmark where the companies are in terms of PdM maturity, a framework has to be developed or utilized. In this thesis, the framework developed by PWC and Mainnovation (Michel Mulders 2018) is used as the main structure and the backbone when placing the companies on a maturity level. Only a few additional criteria are added to get a fuller picture of the actual maturity level. The framework is shown in figure 5.4 below. It is divided up into five different dimensions on the vertical axis. This is Processes, Content, Performance measures, IT, and Organisation. The horizontal axis is divided up into 4 different levels that are: 1. Visual inspection, 2. Instrument inspection, 3. Real-time condition monitoring, and 4. PdM 4.0. To achieve a certain level of maturity, they have to comply with the criteria that make up the matrix between the x and the y axis.

Capability	1. Visual Inspection	2. Instrument Inspection	3. Real Time Condition Monitoring	4. PdM 4.0
Processes	- Periodic inspection (Physical) - Checklist - Paper record	- Periodic inspection (physical) - Instruments - Digital recording	- Continuous inspection (remote) - Sensors - Digital recording	- Continuous inspection (remote) - Sensors and other data - Digital recording
Content	- Paper based condition data - Multiple inspection points	- Digital condition data - Single inspection point	- Digital condition data - Multiple inspection points	- Digital condition data - Multiple inspection points - Digital environment data - Digital maintenance history
Performance Measurement	- Visual norm verification - Paper based trend analysis - Prediction by expert opinion	- Automatic norm verification - Digital trend analysis - Prediction by expert opinion	- Automatic norm verification - Digital trend analysis - Monitoring by CM software	- Automatic norm verification - Digital trend analysis - Prediction by statistical software - Advanced decision support
IT	- MS Excel/MS Access	- Embedded instrument software	- Condition monitoring software - Condition database	- Condition monitoring software - Big data platform - Wifi network - Statistical software
Organisation	- Experienced craftsmen	- Trained inspectors	- Reliability engineers	- Reliability engineers - Data scientists

Figure 5.4: Main maturity framework, [made by author]

Because many of the criteria overlap both in the vertical and horizontal axis, a scorecard for more accurate placement of the companies has been developed with the main framework as the backbone. This scorecard will also ensure a better resolution when assigning a maturity level to the companies and their level in the different dimensions.

Capability	1. Visual Inspection		2. Instrument Inspection		3. Real Time Condition Monitoring		4. PdM 4.0		Total score:
Process (a)	Periodic inspection	1	Periodic inspection	1	Continous inspection	1	Continous inspection	1	
	Checklist	1	Instruments	1	Sensors	0	Sensors and other data	0	
	Paper record	1	Digital recording	1	Digital recording	1	Digital recording	1	4/6 = 67%
Content (b)	Paper based CM data		Digital condition data		Digital condition data	1	Digital condition data	1	
	Multiple inspection points		Single inspection point		Multiple inspection points	1	Multiple inspection points	1	
							Digital environment data	0	
							Digital maintenance history	0	
Performance Measurement (c)	Visual norm verification		Automatic norm verification		Automatic norm verification	1	Automatic norm verificaton	1	
	Paper based trend analysis		Digital trend analysis		Digital trend analysis	0	Digital trend analysis	0	
	Prediction by expert opinion		Prediction by expert opinion		Monitoring by CM software	0	Prediction by statistical software	0	
							Advanced decition support	0	
IT (d)	MS Excel/ MS Access		Embedded instrument software		Condition monitoring software	0	Condition monitoring software	0	
					Condition database	1	Big data platform	0	
							Wifi network	1	
							Statistical software	0	
Organisation (d)	Experianced craftsmen		Trained inspectors		Reliability engineers	0	Reliability engineers	0	
							Data scientists	0	
Total score:		/10		/10		6 /11 55%		6 /17 35 %	

Figure 5.5: Example maturity scorecard, [made by author]

As can be seen from figure 5.5 above, the maturity is getting assessed in both the horizontal and vertical directions. Each of the criteria is matched with an open slot where they can get a "score." The score is either "green," meaning the criteria is fulfilled, red meaning it is not fulfilled, or yellow. If a criteria is marked as yellow, it is either because the criteria have been fulfilled on a higher level, or the criteria do not apply because another higher ranking criteria is fulfilled. Each of the criteria is given a binary value of 1 or 0. When every criteria are given a value and a color, it is possible to sum it up both in the horizontal and vertical directions. As shown in the example scorecard in figure, 5.5 only the green and red values are taken into account when summing up the total in the horizontal direction. This is done so a criteria are only counted once and will ensure a more accurate result. In the vertical axis, the total consists of every number in the column. This is because the criteria are different throughout the vertical axis.

When the scorecard has been filled out for each company, a histogram is made to represent the maturity levels of the total sum, as well as a spider diagram that represents the maturity levels of each of the dimensions. An example of the spider diagram is shown in figure 5.6 below.

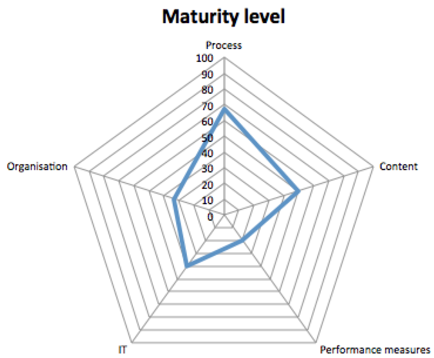


Figure 5.6: Example maturity spider diagram, [made by author]

5.3.2 Høglund

Using the results from the questionnaire as shown in chapter 4, in combination with semi-structured interviews and personal access to the Høglund cloud service solution, it was possible to give Høglund theirs scores on the scoreboard, as shown in figure 5.7 below. The actual results from the questionnaire from Høglund, can be found in the appendix.

Høglund is evaluated on the same level and using the same framework as the other companies, but they have different starting and ending points. This is due to Høglund being the cloud service provider, and the other two companies, Utkilen and Dolphin Drilling, are operational companies. This must be kept in mind when reading the results and the analysis. Directly under figure 5.7, a justification for the scores that are interpretive in the scorecard is given.

Capability	1. Visual Inspection		2. Instrument Inspection		3. Real Time Condition Monitoring		4. PdM 4.0		Total score:
Process (a)	Periodic inspection	1	Periodic inspection	1	Continous inspection	1	Continous inspection	1	
	Checklist	NA	Instruments	1	Sensors	1	Sensors and other data	0	
	Paper record	1	Digital recording	1	Digital recording	1	Digital recording	1	4/5 = 80%
Content (b)	Paper based CM data	1	Digital condition data	1	Digital condition data	1	Digital condition data	1	
	Multiple inspection points	1	Single inspection point	1	Multiple inspection points	1	Multiple inspection points	1	
							Digital environment data	0	
							Digital maintenance history	0	2/4 = 50%
Performance Measurement (c)	Visual norm verification	1	Automatic norm verification	1	Automatic norm verification	1	Automatic norm verificaton	1	
	Paper based trend analysis	0	Digital trend analysis	0	Digital trend analysis	0	Digital trend analysis	0	
	Prediction by expert opinion	0	Prediction by expert opinion	0	Monitoring by CM software	0	Prediction by statistical software	0	
							Advanced decition support	0	1/6 = 17%
IT (d)	MS Excel/ MS Access	1	Embedded instrument software	1	Condition monitoring software	0	Condition monitoring software	0	
					Condition database	1	Big data platform	0	
							Wifi or satalite network	1	
							Statistical software	0	4/7 = 57%
Organisation (e)	Experianced craftsmen	0	Trained inspectors	0	Reliability engineers	1	Reliability engineers	1	
							Data scientists	0	1/4 = 25%
Total score:	6	/9	7	/10	8	/11	7	/17	
		67%		70%		73%		41%	

Figure 5.7: Maturity scorecard Høglund, [made by author]

As can be seen from figure 5.7 above in dimension (a), the continuous inspection is ticked off. This is because the service Høglund is providing is solely based on digitizing instruments and uploading the instrument readings to their cloud. Further, this means that Høglund does not use checklists, but they use instruments and sensors in the form that they have sensorized the instruments. They do collect some other data except from the sensor readings, but not enough to satisfy the criteria "sensors and other data." Everything they collect is recorded digitally.

In dimension (b), they have digital condition data in the form of the sensorized instruments, and they have multiple inspection points. These two criteria are ticked off, but they both have improvement potential. As of now, Høglund is mostly collecting pressure and temperature data. These data types are useful in a short-term perspective but are not as valuable when predicting the future state in the long term. As of today, Høglund collects some environmental data, but not enough for the criteria to be checked off. They do not keep any digital maintenance record.

In dimension (c), the only criteria they satisfy are the visual and automatic norm verification. They do not make any predictions of the future state or trend analysis.

In dimension (d), they satisfy the first criteria by using MS Excel for storing and uploading their sensor data. The Excel file is a live document connected to an embedded instrument software program that Høglund is providing its customers. This means that they also satisfy the criteria regarding the condition database and the network criteria. They are using satellite services for uploading the instrument data from the ships to the cloud service.

Last in dimension (e), the only resources of people Høglund has internal access to are, reliability engineers.

Below in figure 5.8 a representation of the horizontal maturity level of the different dimensions is shown in the form of a spider diagram. As can be seen, the weakest dimensions for Høglund at this point are dimension (c) "Performance measurement" and dimension (e) "Organisation." Their most robust dimension is (a) "Process," with a score of 80 out of 100.

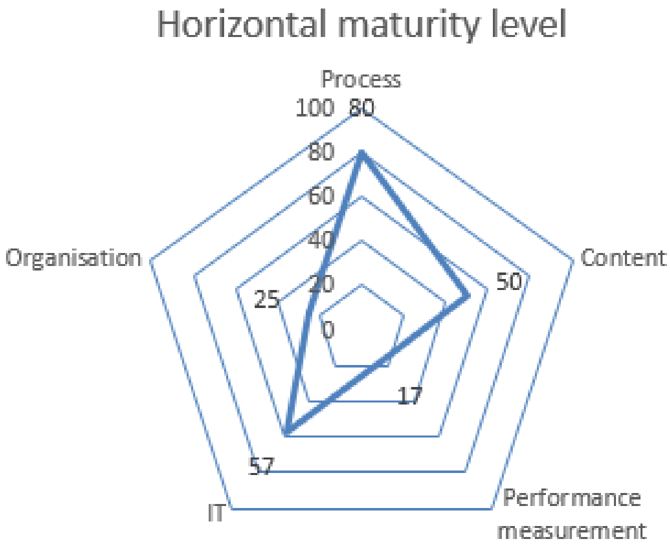


Figure 5.8: Spider diagram of Høglund's horizontal maturity levels, [made by author]

Below in figure 5.9 we can see the vertical maturity levels and how much of each of the levels Høglund is satisfying. They are overall high on levels 1, 2, and 3, with level 3 as the highest. On level 4, they only get a score of 41 out of 100. Therefore, as an overall level, they would be considered to be on level 3.

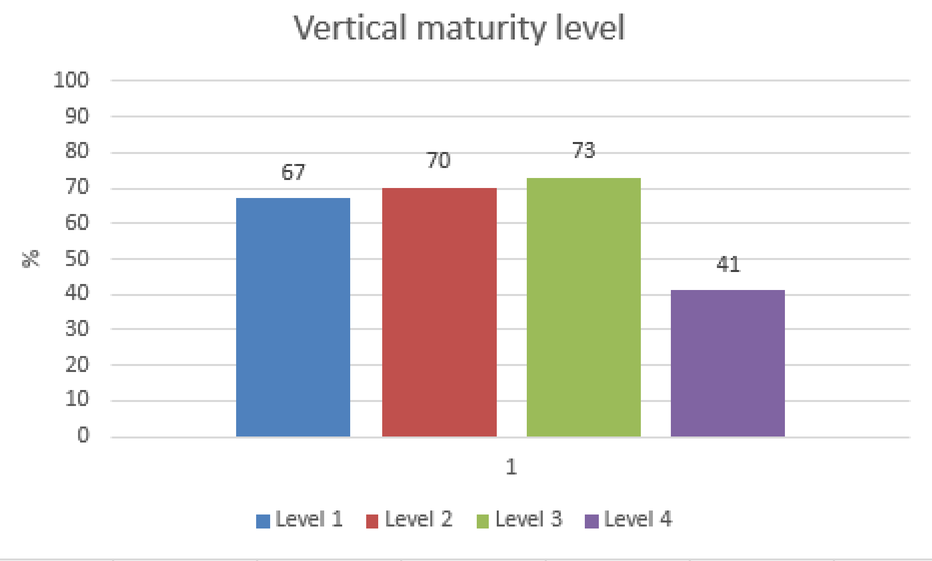


Figure 5.9: Histogram of Høglund's vertical maturity levels, [made by author]

5.3.3 Utkilen

The results in the scorecard shown in figure 5.10 below are based upon the results from the questionnaire, semi-structured interviews, and access to the cloud service that Høglund is providing Utkilen. Utkilen's answer to the questionnaire is shown in the appendix.

Utkilen is an operational company that uses Høglund´s cloud service. Therefore, they have a different perspective than Høglund but are evaluated on the same criteria and using the same framework. Below the scorecard is a justification for the values given to Utkilen´s maturity.

Capability	1. Visual Inspection		2. Instrument Inspection		3. Real Time Condition Monitoring		4. PdM 4.0		Total score:
Process (a)	Periodic inspection	1	Periodic inspection	1	Continous inspection	0	Continous inspection	0	4/6 = 67%
	Checklist	0	Instruments	1	Sensors	1	Sensors and other data	0	
	Paper record	0	Digital recording	1	Digital recording	1	Digital recording	1	
Content (b)	Paper based CM data	0	Digital condition data	1	Digital condition data	1	Digital condition data	1	3/4 = 75%
	Multiple inspection points	1	Single inspection point	1	Multiple inspection points	1	Multiple inspection points	1	
							Digital environment data	0	
							Digital maintenance history	1	
Performance Measurement (c)	Visual norm verification	1	Automatic norm verification	0	Automatic norm verification	0	Automatic norm verificaton	0	3/7 = 43%
	Paper based trend analysis	0	Digital trend analysis	1	Digital trend analysis	1	Digital trend analysis	1	
	Prediction by expert opinion	1	Prediction by expert opinion	1	Monitoring by CM software	0	Prediction by statistical software	0	
							Advanced decition support	0	
IT (d)	MS Excel/ MS Access	1	Embedded instrument software	1	Condition monitoring software	0	Condition monitoring software	0	4/7 = 57%
					Condition database	1	Big data platform	0	
							Wifi or satalite network	1	
							Statistical software	0	
Organisation (e)	Experianced craftsmen	1	Trained inspectors	1	Reliability engineers	0	Reliability engineers	0	2/4 = 50%
							Data scientists	0	
Total score:	6	/10	9	10	6	/11	6	/17	
		60%		90%		55%		35%	

Figure 5.10: Maturity scorecard Utkilen, [made by author]

As shown in figure 5.10 above, in dimension (a), Utkilen relies mainly on periodic inspections. They have instruments and the sensorization of them using the Høglund solution, but this does not cover most of the inspection points they need. However, they have a digital recording system in place.

In dimension (b), Utkilen satisfies the criteria of having a digital maintenance record. In addition to this, they satisfy all the other criteria as Høglund due to them running a Høglund system.

In dimension (c), Utkilen does have a visual norm verification but claims it is not automatic. This might be because when they answered the questionnaire, they were thinking of their whole system, and not just the system that Høglund is providing them. What gives them an overall higher score in this dimension compared to Høglund is that they do some digital trend analysis performed by experts they have access to.

In dimension (d), they get the same score as Høglund got in their scorecard. This is due to Utkilen using the IT solution provided by Høglund, and will therefore get the same result as them.

In dimension (e), we see that Utkilen has access to other types of personnel than Høglund but on a lower maturity level. This gives them a higher score in this dimension because they have more than one type of personnel that can contribute with knowledge and insights regarding their assets.

In figure 5.11 below, we can see that Utkilen, for the most part, is half integrated when it comes to the different dimensions. With their lowest score being dimension (c) "performance measurement" and their highest score being dimension (b) "content."

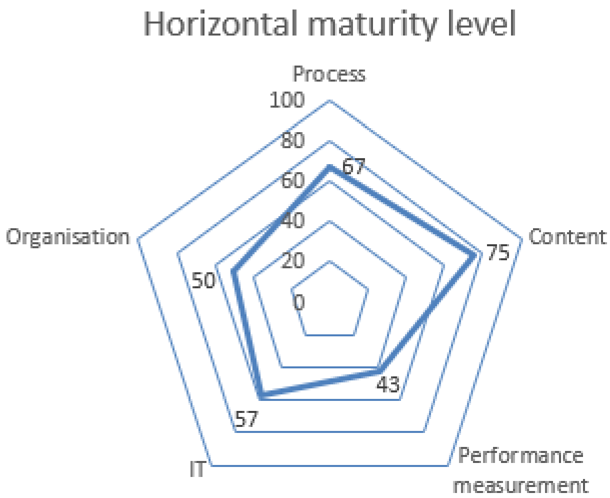


Figure 5.11: Spider diagram of Utkilen's horizontal maturity level, [made by author]

Below in figure, 5.12 an overview of the total vertical maturity scores from Utkilen is shown. Level 2 is the most prominent level, with an overall score of 90 out of 100. The scores get gradually lower as the maturity levels get higher. As an overall maturity level score, they will be on a low level 3.

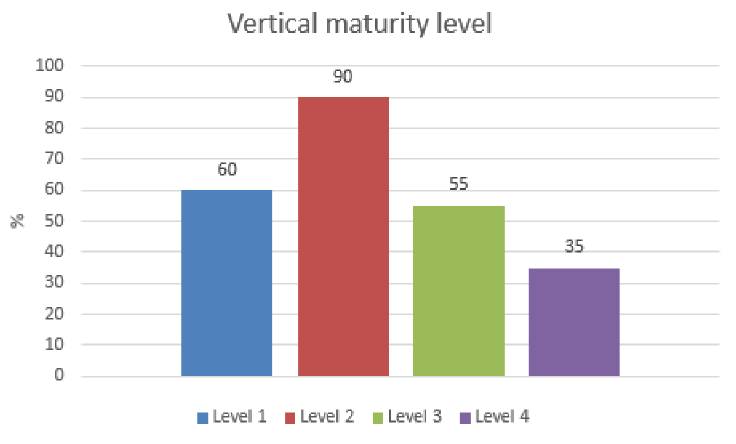


Figure 5.12: Histogram of Utkilen's vertical maturity level, [made by author]

5.3.4 Combined maturity of Høglund and Utkilen

Since Høglund and Utkilen are on opposite sides of the customer and provider scale, they complement each other in some areas. Because of this, a separate scorecard is filled out, showing the combined maturity of Høglund and Utkilen. This is shown in figure 5.13 below. The results from the scorecard are based on the answers from both of the companies in the two questionnaires and semi-structured interviews and experiences gained from using the Høglund cloud service system with Utkilen as the customer. Below figure 5.13, a justification for every dimension is shown and explained.

Capability	1. Visual Inspection		2. Instrument Inspection		3. Real Time Condition Monitoring		4. PdM 4.0		Total score:
	Periodic inspection	1	Periodic inspection	1	Continous inspection	1	Continous inspection	1	
	Checklist	0	Instruments	1	Sensors	1	Sensors and other data	0	
Process (a)	Paper record	1	Digital recording	1	Digital recording	1	Digital recording	1	4/5 = 80%
	Paper based CM data	1	Digital condition data	1	Digital condition data	1	Digital condition data	1	
	Multiple inspection points	1	Single inspection point	1	Multiple inspection points	1	Multiple inspection points	1	
							Digital environment data	0	
Content (b)							Digital maintenance history	1	3/4 = 75%
	Visual norm verification	1	Automatic norm verification	1	Automatic norm verification	1	Automatic norm verificaton	1	
	Paper based trend analysis	0	Digital trend analysis	1	Digital trend analysis	1	Digital trend analysis	1	
	Prediction by expert opinion	1	Prediction by expert opinion	1	Monitoring by CM software	0	Prediction by statistical software	0	
Performance Measurement (c)							Advanced decition support	0	3/6 = 50%
	MS Excel/ MS Access	1	Embedded instrument software	1	Condition monitoring software	0	Condition monitoring software	0	
					Condition database	1	Big data platform	0	
							Wifi or satalite network	1	
IT (d)							Statistical software	0	4/7 = 57%
	Experianced craftsmen	1	Trained inspectors	1	Reliability engineers	1	Reliability engineers	1	
Organisation (e)							Data scientists	0	3/4 = 75%
Total score:	8	/10	10	10	9	/11	9	/17	
		80%		100%		82%		52%	

Figure 5.13: Combined maturity scorecard of Utkilen and Høglund, [made by author]

As can be seen from figure 5.14, the overall scores are higher when the two companies are accessed as a combination. In dimension (a), we see that every criteria are fulfilled except the "sensors and other data" this is because neither Høglund nor Utkilen is collecting enough other data from the system that Høglund is providing to satisfy the criteria.

In dimension (b), every criteria are fulfilled except the digital environment data. The multiple inspection points are satisfied in terms of the scorecard but have room for improvement. As discussed under the Høglund scorecard, the inspection points mainly consist of pressure and temperature data.

In dimension (c), we see that all the same criteria have been fulfilled as in the scorecard with Utkilen, and in addition, the automatic norm verification is fulfilled. However, neither Utkilen nor Høglund is providing CM software, predictions, or any decision support.

In dimension (d), the score on the scorecard is the same as both in Høglund's and Utkilen's scorecard.

In the last dimension (e), there is some improvement combining both companies. Here we can see that they have access to all necessary personnel, except data scientists.

In figure 5.14 the combined horizontal maturity level of Høglund and Utkilen is shown for the different dimensions. As can be seen, the overall maturity is higher when they are accessed together in contrast to separate. They show an overall high maturity level with 75% and 80% in dimensions (a), (b), and (e). However, they are still only reaching around 50% for the remaining two dimensions.

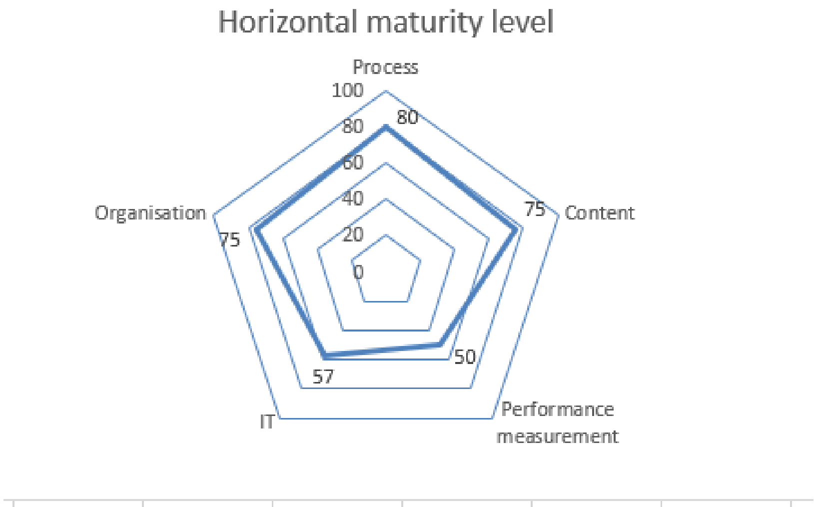


Figure 5.14: Combined Spider diagram of Utkilen and Høglund‘s horizontal maturity level, [made by author]

Below in figure 5.15 a histogram showing the vertical maturity levels from the scorecard is shown. This shows a significant improvement in comparison to the individual maturity levels of the companies. As can be seen, level 2 is fully implemented, and a high score of 82% is given to level 3 and a score of 52% integration in level 4. This places them overall in a high level 3 or a low level 4. With level 3 or 4 as a starting point, it shows great promise and opportunity to develop the solutions further.

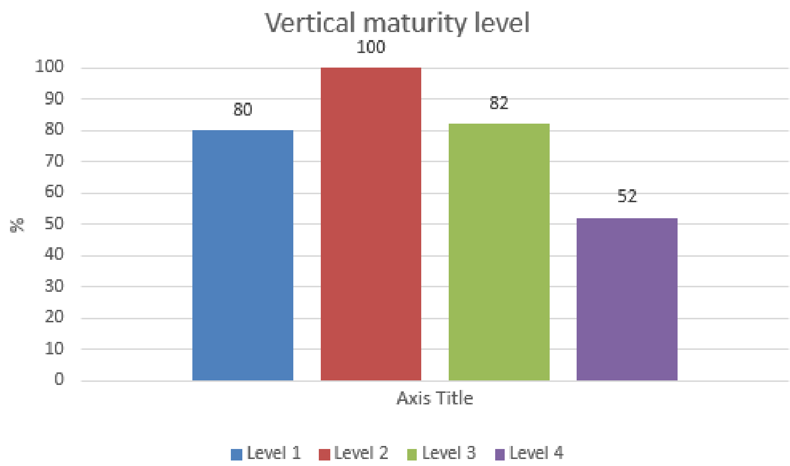


Figure 5.15: Combined histogram of Utkilen and Høglund‘s vertical maturity level, [made by author]

5.3.5 Dolphin drilling

For validity purposes and investigating if the maturity level of Utkilen is an outlier or not, the maturity levels of Dolphin Drilling have been accessed as well. Since Dolphin Drilling is an oil drilling company, they are on some levels fundamentally different then Utkilen. The similarities in their needs and requirements, however, is overlapping with Utkilen. They also have some of the same assets on board as Utkilen, for example, their diesel generator. At Utkilen, the engines are used for propulsion, and on Dolphin Drilling‘s platforms, it is used to generate electricity. However, they need a system that Høglund is providing and could provide in the future.

The scorecard for Dolphin Drilling is shown below in figure 5.16. The information to fill it out has been collected using the same questionnaire as Utkilen and a semi-structured interview. The answers to the questionnaire are attached in the appendix.

Below figure 5.16, a justification for the criteria is shown and described.

Capability	1. Visual Inspection		2. Instrument Inspection		3. Real Time Condition Monitoring		4. PdM 4.0		Total score:
Process (a)	Periodic inspection	1	Periodic inspection	1	Continous inspection	0	Continous inspection	0	4/6 = 67%
	Checklist	1	Instruments	1	Sensors	1	Sensors and other data	0	
	Paper record	0	Digital recording	1	Digital recording	1	Digital recording	1	
Content (b)	Paper based CM data	0	Digital condition data	1	Digital condition data	1	Digital condition data	1	3/4 = 75%
	Multiple inspection points	1	Single inspection point	1	Multiple inspection points	1	Multiple inspection points	1	
							Digital environment data	0	
							Digital maintenance history	1	
Performance Measurement (c)	Visual norm verification	1	Automatic norm verification	1	Automatic norm verification	1	Automatic norm verificaton	1	2/6 = 33%
	Paper based trend analysis	0	Digital trend analysis	0	Digital trend analysis	0	Digital trend analysis	0	
	Prediction by expert opinion	1	Prediction by expert opinion	1	Monitoring by CM software	0	Prediction by statistical software	0	
							Advanced decition support	0	
IT (d)	MS Excel/ MS Access	1	Embedded instrument software	1	Condition monitoring software	0	Condition monitoring software	0	3/7 = 43%
					Condition database	1	Big data platform	0	
							Wifi or satalite network	0	
							Statistical software	0	
Organisation (e)	Experianced craftsmen	1	Trained inspectors	1	Reliability engineers	0	Reliability engineers	0	2/4 = 50%
							Data scientists	0	
Total score:	7	/10	9	10	6	/11	5	/17	
		70%		90%		55%		29%	

Figure 5.16: Maturity scorecard Dolphin drilling, [made by author]

As can be seen in figure 5.16, Dolphin Drilling satisfy many of the same criteria as Utkilen. In fact, they are identical in the dimensions (a) "process", (b) "content" and (e) "organisation. Where they differ is in the remaining two dimensions.

In dimension (c), "performance measurement," Dolphin Drilling gets a lower score than Utkilen. This is due to them not doing any trend analysis. Neither on paper or digitally. All predictions they make are based upon expert opinions and not on CM software or statistical software. However, they do have automatic norm verification on their inspection points.

In dimension (d) "IT," Dolphin drilling gets a lower score than Utkilen. This is due to Dolphin Drilling not having a WiFi or satellite solution for relaying the collected data from their embedded instrument software.

In figure 5.17 below, the total score regarding the dimensions is shown in a spider diagram. From the diagram, we can see that the overall score is around 50%, but with some exceptions. In dimension (b), they score as high as 75%, but in dimension (c), they only score 33%.

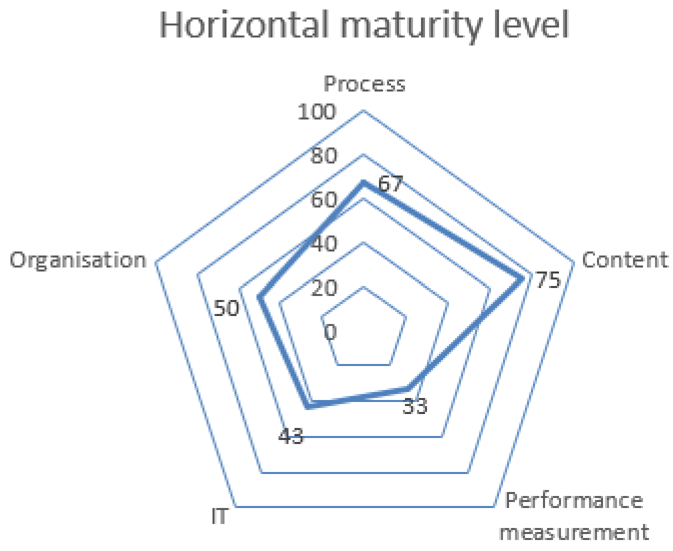


Figure 5.17: Spider diagram of Dolphin drilling‘s horizontal maturity level, [made by author]

Below in figure 5.18 the percentage of each of the vertical maturity levels is shown. As shown in the figure, level 2 is almost fully integrated with 90%, followed by level 3 at 55% and level 4 at 29%. This places Dolphin Drilling at an overall low level 3. In total, they are very similar to Utkilen in their maturity and what needs to be addressed to get to a higher level.

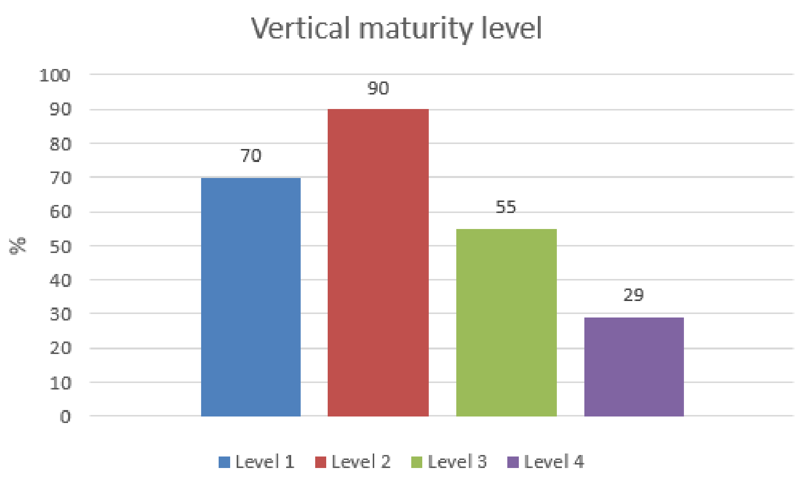


Figure 5.18: Histogram of Dolphin drilling‘s vertical maturity level, [made by author]

5.4 Gap analysis

In this section, an analysis of the gap between the companies' present state and their goal of reaching level 4.0 is shown. This will help to assess what is the missing parts reaching the level and how they can be addressed. As shown in figure 5.19 below, a methodical approach to the gap analysis is used to ensure that all important elements are considered. The first is pinpointing the current state of the companies. This will be done using the maturity analysis as a background. Then the future state or the end goal is accessed. This is partly done using the maturity framework, as well as the needs and requirements analysis. Having both the current state and the end goal, it is possible to identify the gap. Last, improvements to close the gap are identified and assessed.

Since Dolphin Drilling is only a part of the maturity analysis for comparison with Utkilen and validity, it is not included in the further analysis. Instead, the gap analysis will focus on Høglund and how they can improve their services to their customers like Utkilen. Even though Høglund and their cloud service system is the main focus in the further analysis, it is essential to know what features Utkilen has to access how and what Høglund needs to improve and further develop.

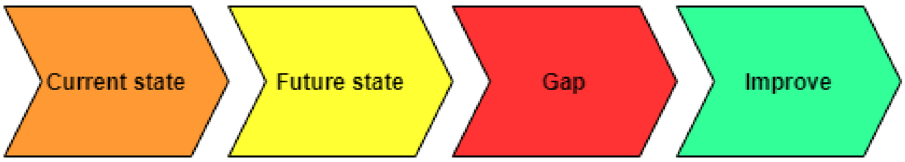


Figure 5.19: Gap analysis overview, [made by author]

5.4.1 Current state, future state, and Gap

As shown in figure 5.20 below, the current state of every dimension regarding Høglund's maturity is shown in orange. The missing parts to achieve 100% maturity in the separate dimensions, with the existing framework, are shown in red for each dimension. The red is what makes up the gap that needs to be filled and addressed to reach level 4.0.

Current state

Currently, Høglund is offering a so-called embedded instrument software to their customers and the surrounding infrastructure to make this work and the installation of sensors to monitor the existing systems on a ship. Thus, they already have the backbone necessary to develop further and evolve their cloud service to incorporate PdM. Below, a list of every dimension and Høglund's state in each of them is accounted for.

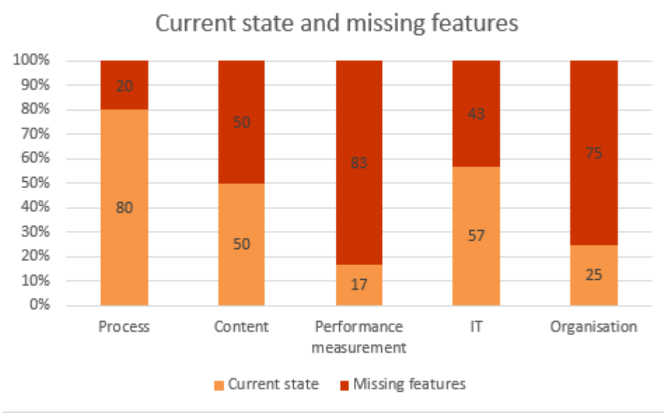


Figure 5.20: current state and missing features at Høglund, [made by author]

- **Process**

  In dimension (a) "Process," Høglund has almost reached 100% of its potential. They have a lot of the necessary infrastructure in place but are lacking in the types of data they are collecting. They have continuous inspection of the assets by digital instruments and sensors that are recorded digitally.

- **Content**

  In dimension (b) "Content," Høglund also has a lot of the background necessary but falls short in some crucial areas. They do digital recording of all the data they collect and collect data at multiple points for each of the assets. However, the data they are collecting for the main engines onboard the ships is mainly pressure and temperature. They also do not collect and have a service that could incorporate the digital maintenance history, which is something Utkilen does themself at this point. Last, Høglund is collecting digital environment data but has room for improvement and could collect more.

- **Performance measurement**

  In dimension (c), "Performance measurement," they get a very low score. This is because all they have that satisfy the criteria in this dimension is the automatic norm verification. This is both visual and automatic in the form that certain thresholds are set for the parameters they are monitoring. For example, there is set an allowable deviation on the temperature sensors that monitor the cylinders in Utkilen's ships. If the values are outside the threshold, an alarm will set off warning about it.

  What they are lacking is everything else in this dimension. For example, Høglund does not do any trend analysis of the values in their system. For the time being, this is something Utkilen does themselves, but only by the use of expert opinion. Høglund also lacks CM software, digital trend analysis, predictions by statistical software, and decision support.

- **IT**

  In dimension (d) "IT," Høglund does at the moment have an embedded instrument software, a condition database in Excel, and remote access to their sensors. At the moment, they are relaying their sensor data by the use of satellites from the ships up into the cloud. What they do lack are CM software, statistical software, and a big data platform.

- **Organisation**

  In dimension (e) "Organisation," they have access to reliability engineers internally in Høglund. However, they lack access to both data scientists, trained inspectors, and experienced craftsmen.

Future state

The future state or the goal for Høglund is derived from the needs and requirements analysis, the questionnaire, semi-structured interviews, and the PWC framework. As stated in the research question, the goal for Høglund is to reach a maturity level of PdM 4.0, so their cloud service can be used for predictive maintenance. To archive this, all the criteria in level 4 of the maturity framework should be fulfilled. Even if it might be challenging to implement all the features, the end goal should still be to archive 100% implementation at the end in level 4, as well as having some of the criteria from the lower levels. Below in table 5.2 all the necessary criteria are stated.

Table 5.2: Future state criteria requirements, [made by author]

Process	**Content**	**Performance measurement**	**IT**	**Organisation**
Continous inspection	Digital condition data	Automatic norm verification	Embedded insturment software	Reliability engineers
Sensors and other data	Multiple inspection points	Visual norm verification	Condition monitoring software	Data scientists
Digital recording	Digital environment data	Digital trend analysis	Condition database	
Instruments	Digital maintenance history	Monitoring by CM software	Big data platform	
		Predictions by statistical software	WiFi or satalite network	
		Advanced decition support	Statistical software	

Gap

By examining both the current and future state, a gap between them is possible to identify. As shown in table 5.3, all the criteria needed for a full implementation are shown. In orange, we see the already present criteria, and the gap is shown in red representing all the criteria that are still not implemented. Another additional criteria that can be considered a gap are using AI as a resource for processing the collected data.

Table 5.3: Full implementation gap, [made by author]

Process	Content	Perforemance measurement	IT	Organisation
Continous inspection	Digital condition data	Automatic norm verification	Embedded insturment software	Reliability engineers
Sensors and other data	Multiple inspection points	Visual norm verification	Condition monitoring software	Data scientists
Digital recording	Digital environment data	Digital trend analysis	Condition database	
Instruments	Digital maintenance history	Monitoring by CM software	Big data platform	
		Predictions by statistical software	WiFi or satalite network	
		Advanced decition support	Statistical software	

5.4.2 Improvements

Now that the current and future state is determined and a clear "gap" between them is defined, several solutions can be suggested to close the gaps in each dimension. Since the improvements are only concerning Høglund and they do not own the assets themselves, but rather provide solutions for their customers, Utkilen and their assets will be used as the example assets. Since this is mainly regarding the conceptual, and the process of improvements can be replicated for any asset, the main focus asset will be the main diesel engine. This is also something that Dolphin Drilling has onboard their platforms. Therefore, the same modifications that are suggested done to Utkilens main engine can be replicated and done to Dolphin Drilling´s platforms as well. Below, every dimension will be addressed, and solutions to the criteria that are not fulfilled will be given.

Process

- Sensors and other data

To address the lacking criteria, that is, "sensors and other data," a definition of "other data" needs to be given. Unfortunately, in the PWC and Mainnovation document, (Michel Mulders 2018) the criteria "sensors and other data" are not defined in any way. This leaves the reader to make assumptions themselves of what other data means. In this thesis, it is defined as data that are relevant from a maintenance perspective that is collected by other means than by the use of sensors.

One of the improvements Høglund could do to their system is to make it compatible with the existing Enterprise Resource Planning (ERP) systems that many of Høglund´s customers already use. An example of a system like this is SAP. In an ERP system, all the corrective and preventive maintenance done to the asset could be logged and stored.

Content

- Digital maintenance history

The first criteria that need to be addressed in the contents dimension are the "digital maintenance history" criteria. The solution here is the same as the solution for the missing criteria in the process dimension. By making the Høglund system "talk" with an ERP system, the maintenance history would be accessible and used for later analysis by Høglund.

- Digital environment data

The following criteria that need to be addressed are the digital environment data collection. Also, here we need a definition of the criteria. The definition used in this thesis is as follows; everything that affects the asset that can be used for analysis in regards to predictive maintenance.

This is something Høglund is doing at the moment, but not to the extent of its full potential. This is the reason the criteria are "dotted" in the gap analysis. Høglund is collecting data about the speed of the vessel, location, weather conditions, etc. To get a fuller picture of the environment, Høglund could, for example, also be collecting water temperatures, air humidity, air temperature, etc.

- Multiple inspection points

This criteria is also "dotted" because it technically is implemented, but not in a way that gives many advantages to predictive maintenance. As discussed many times before, the "multiple inspection points" criteria are fulfilled by Høglund having many sensors on their customer's assets, but not the type of sensors that will give the ability to make long-term predictions of the health of the assets. The sensors that are in use at the moment are mostly pressure and temperature.

To make long-term predictions, the features that are monitored must slowly degrade over time and not change by the hour. Typical failure modes that progress over time are; vibration, audio, and oil values. For a diesel engine, the big rotating parts that can be monitored using vibration are the camshaft, main shaft, and main bearings. As can be seen from the Pareto chart in figure 5.21 below, the main maintainable item that causes downtime is the main bearing. This then suggests that the main bearing is a good place to start when implementing vibration sensors to the main engine.

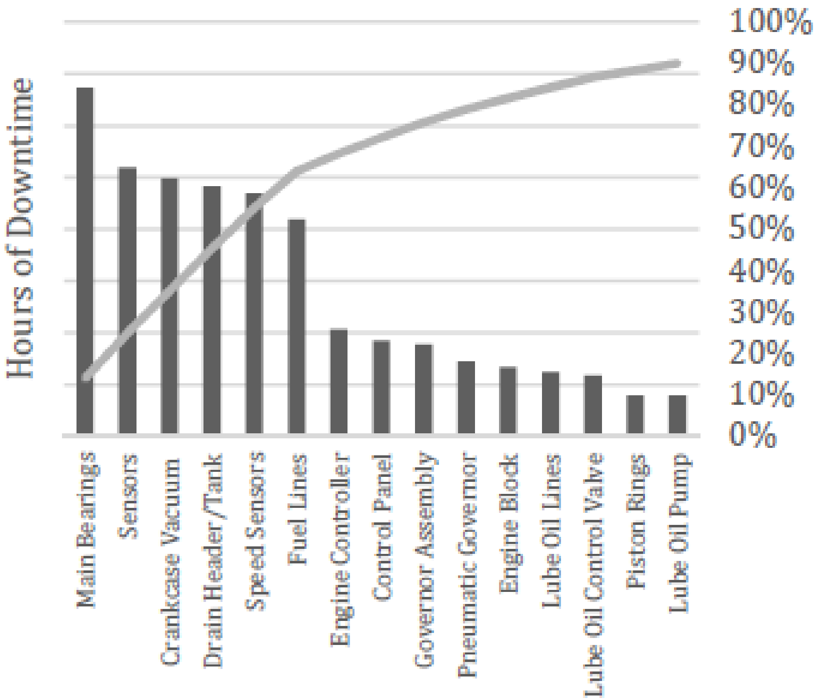


Figure 5.21: Maintainable items VS Downtime, (Steve Nixon 2018)

The sensor used to collect vibration data is usually an accelerometer that will measure the relative movement within the bearing. The sensors are small and can most often be retrofitted to the engine. If there is not enough room for a retrofit of the sensors on the bearings, an option is to place the vibration sensor somewhere near the bearing where the vibration would be transmitted through the casing.

Another type of sensor that would benefit the shipowner of having that can be used for predictive manners is an oil debris sensor. From the semi-structured interviews, the technical manager of Dolphin Drilling is saying that they do oil samples that are analyzed for debris. However, they are sent onshore for analysis, and the result is sent back to the rig. This process takes time and does not give the ability to make a trend analysis with a good enough resolution for predictions. This can be solved by fitting an oil debris sensor directly to the oil line, as shown in the theoretical background chapter.

Performance measurement

- Digital trend analysis

Digital trend analysis can easily be accomplished when suitable sensors are in place that gives values that are worth monitoring and trending over time. This can either be done in Excel or directly in CM software.

- Monitoring by CM software

The system that Høglund has up and running now is, per definition, a condition monitoring software. It is not marked in orange in the gap section because it lacks a few of the core functionalities that should be present. Mainly this is the analysis of the collected data and access to the valuable data for predictions and trend analysis. By further developing the Høglund system to incorporate trend analysis, predictions, and decision support, it will truly become a useful tool for predictive maintenance purposes.

- Predictions by statistical software

When having access to the correct data, meaning vibration data and oil debris data, through the Høglund system, statistical software can enhance the predictions and clarify patterns present in the collected data. This is either something that Høglund could develop themself, or they could make their system compatible with another system that could make the statistical prediction. The statistical predictions could, for example, be regression analysis or anomaly analysis.

- Advanced decision support

When using a system like the Høglund cloud service system, it might be challenging to see the present patterns and make decisions from the available data. Advanced decision support with more than just the maintenance data would be a great advantage for the system's decision-maker. The other data that could be feed into the system could, for example, be the location of the ships, their planned arrival, and departure from harbors. This would make it possible to plan when the maintenance should be done and in what location. Since the spare parts needed are not available in every harbor, it will be a great advantage if the software could process all this data and suggest where the worn-out parts should be changed.

IT

Since both CM software and statistical software are discussed under subsection "Performance management, it is unnecessary to repeat it in the IT section.

- Big data platform

The definition of a big data platform is when the amount of data on the platform is too much to process for a standard computer. It is often a platform that has multiple databases linked to it. Høglund is on its way to this scale but still has some functionalities that need to be addressed. For the Big Data platform to work, it needs to be compatible with other software and other databases. For example, an ERP system, decision-making software, and CM software. This is entirely possible to obtain but requires the structure of the platform and the data in it to be in a format that is useful for other systems.

Organisation

- Data scientists and access to other personnel

What Høglund does not have access to internally, according to the questionnaire, is data scientists. If they plan to develop the cloud service system further to be used for predictions, they will need this in the future. Either hire someone, use consultants or make a joint venture with another company that has this expertise.

Other valuable personnel that is useful in the process of evolving their cloud service are trained inspectors and experienced craftsmen. It is at least essential to consult with people that have hands-on and first-hand experience.

AI

The last stage that is not on the PWC framework is the use of AI. This is a relatively new technology but shows great potential for automating real-time data analysis and making predictions from the collected data. Machine learning is a potential technology that could be used instead of or in addition to statistical software and advanced decision support. From the questionnaire, Høglund said that they are already teamed up with an external company called "DIPAI," which specializes in diagnostics and prognostics using artificial intelligence.

5.4.3 Prioritization

When the gap and the necessary improvements have been identified, as seen in the previous subsections, the improvements have to be prioritized. This is done, so Høglund has the opportunity to focus their resources where it is needed. Below in table 5.4, a prioritization table is shown, followed by why the prioritization is in this particular order. As can be seen from the table, it is divided up into prioritization A and B. A has a higher priority than B and should all be fulfilled before implementing features from section B. Both A and B are also prioritized from 1 to 5.

Table 5.4: Prioritisation table, [made by author]

Pri:	A	B
1	Sensors and other data	Data scientists
2	Multiple inspection points	Big data platform
3	Digital maintenance history	Digital trend analysis
4	Digital environment data	Statistical software and decition support
5		Condition monitoring software

As shown in the table above, everything in column A has to do with creating data or making the data available for further analysis. Data creation and systematizing have the highest priority because, without the correct data, there is no point in having advanced analysis tools. In column B the data scientist and Big data platform are at the top of the list. This is because the infrastructure and knowledge needs to be available to expand computer software and analysis tools further. After the two first in list B is completed, it is followed by increasingly more advanced analysis methods and tools.

5.5 SWOT analysis

As shown in figure 5.22 below, the SWOT analysis is conducted to get an overview of the strengths, weaknesses, opportunities, and threats associated with Høglund's cloud service solution. The SWOT analysis is conducted with a holistic view, including the technical short terms and possible long-term evolvement. Below the figure, all the dimensions that are listed in the SWOT diagram are explained.

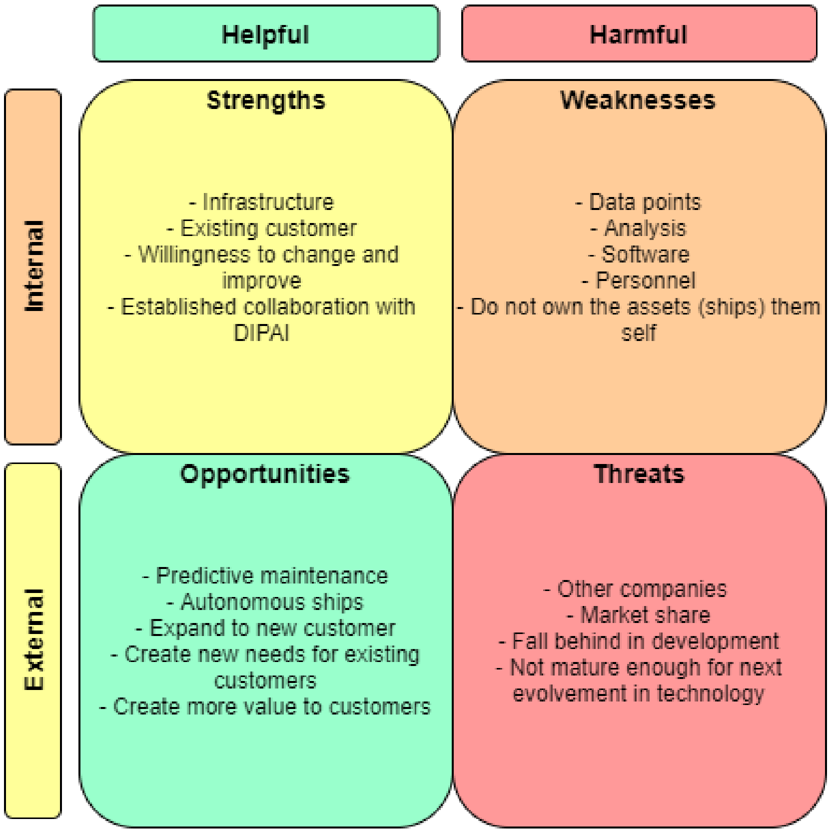


Figure 5.22: SWOT analysis of Høglund, [made by author]

5.5.1 Strengths

As can be seen in the upper left square in the SWOT diagram, the strengths of the existing solutions that Høglund offers are shown. Below in the list, everything in the dimension is explained.

- Infrastructure

  As discussed in the gap analysis, Høglund has many of the main points regarding their infrastructure that are necessary to do predictive maintenance. For example, they have an existing cloud, some sensors, remote access by satellite, and a database. This is a good foundation for further evolvement to PdM.

- Existing customers

  Another strength is that Høglund already has multiple existing customers using the cloud solution they are offering. If Høglund were to expand their services to include PdM, it would be easier to sell this to existing customers rather than new customers.

- Willingness to change and improve

  From the questionnaire, one of the questions is if they are willing to change and improve their services. On this question, we can see that both Høglund and Utkilen are willing and eager to change, evolve and improve. This is a good indication that the evolvement towards PdM is the right move for Høglund.

- Established collaboration with DIPAI

  In the questionnaire, we can also see that Høglund recently has started a collaboration with a company called DIPAI. This is a company that offers diagnostics and prognostics using AI. Since DIPAI hold valuable and deep knowledge of computer science and AI, it is a good collaboration partner for Høglund since they do not hold this knowledge themself.

5.5.2 Weaknesses

As can be seen in the upper right square in the SWOT diagram, the weaknesses of the existing solutions that Høglund offers are shown. Below in the list, everything in the dimension is explained.

- Datapoints

  As said many times before in the thesis, one of the significant weaknesses for Høglund is the types of data they are currently collecting from the ships. If Høglund wants to move into PdM as one of their areas of expertise, they need to collect more slow-developing data. For example, vibration data or oil debris data.

- Analysis

  Another weakness of Høglund is that they are not analyzing the data they are currently collecting. Not doing so is understandable considering the types of data they are collecting, but it is still something they could evolve.

- Software

  Since the software Høglund is providing their customers with is mainly for display purposes, it lacks background analysis. For example, statistical software, trend analysis, and so on. This is explained more in dept in the gap analysis.

- Personnel

  Also, as said in the gap analysis, Høglund lacks the right personnel to evolve further and take full advantage of new technology like PdM and AI. This is why they need to team up with other companies like DIPAI.

- Do not own the assets (ships) themself

  The last weakness in this dimension is that Høglund is a service company and does not own the assets themself. In this case, the assets are mainly the ships. The downside to not owning the ships themself is that it makes it harder to conduct R&D when expanding the functionalities in their cloud service. They are therefore reliant on a collaboration with another company that owns the ships for R&D.

5.5.3 Opportunities

As can be seen in the lower-left square in the SWOT diagram, the opportunities that lie in Høglund‘s future are shown. Below in the list, everything in the dimension is explained.

- Predictive maintenance

  Implementing PdM as an added functionality to Høglund services would give them more to offer their customers. Doing so would make Høglund more intertwined with the customers and therefore make a stronger bond and make the customers more reliant on Høglund.

- Autonomous ship

  As technology advances, autonomous ships will become a more and more realistic option for ship owners worldwide. If the ships become autonomous, it will most likely not be any personnel on board the ships. Therefore, the shipowner will be reliant on remote systems like the one Høglund is offering as well as predictive maintenance.

- Expand to new customers

  By evolving the service that Høglund is offering, they will be able to expand their customer base. With added functionality like PdM, they could reach customers who are not interested in the solutions they are offering today but want a new version, including PdM.

- Create new needs for existing customers

  By offering added functionality, Høglund could create new needs for their customer that they did not know they needed but see the appeal to when presented with it.

- Create more value to customers

  By added functionality, the customers will get more value by being or becoming a Høglund customer. This will, in turn, mean more customers and more income per customer for Høglund.

5.5.4 Threats

As can be seen in the lower right square in the SWOT diagram, the threats that lie in Høglund‘s future are shown. Below in the list, everything in the dimension is explained.

- Other companies

  One of the biggest threats for Høglund is other companies that are operating in the same market as them. Many companies offer PdM as a functionality to their cloud service. Therefore Høglund needs to distinguish itself by either offering superior quality, lower prices, or a more holistic solution consisting of many functions.

- Market share

  By operating within a market of many companies, Høglund is heavily competing for market share. The market share can be protected and gained by the strategies explained above.

- Fall behind in development

  Another threat is that the maturity gap becomes too big for Høglund to close. If they do not include, for example, PdM as one of their functions, they might loos market share by customers going to other competing service companies. If Høglund waits too long to implement and gain a level 4.0, there might be a scenario where the barriers to becoming a market leader are too high, and other companies already saturate the market.

- Not mature enough for next evolvement in technology

  The last threat is that if they do not keep up with the technological evolvement that is taking place today, the gap becomes even larger, and they will not be able to close the gap in the future. This is especially true when it comes to the next evolvement in the shipping industry that might be autonomous ships.

5.6 Overall analysis

As was shown on the first page of the analysis and below in figure 5.23, the Maturity, Gap, and SWOT analysis are connected and will affect each other as they change. The change will not affect the first two steps unless a paradigm shift occurs or Høglund decides to change its objective towards PdM.

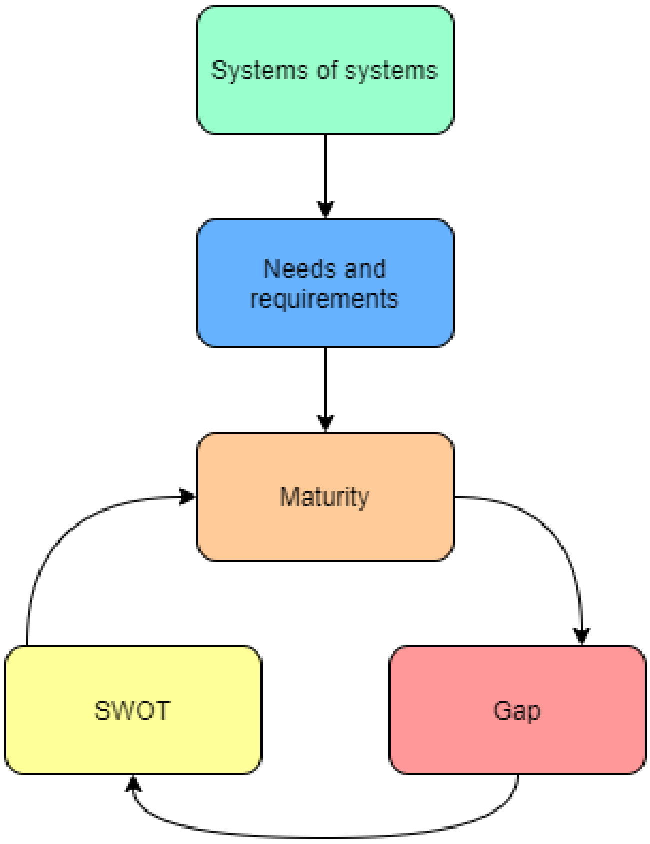


Figure 5.23: Process chart of the 5 analysis steps, [made by author]

If, for example, Høglund improves their PdM abilities by installing vibration sensors, it will make Høglund‘s maturity go up. At the same time, it will close several gaps in the gap analysis. At last, it will make a shift in the SWOT analysis, shifting some of the weaknesses for strengths. This pattern will repeat until Høglund has reached a level of PdM 4.0.

Chapter 6

Discussion

The purpose of the discussion chapter is to look at the work, methods, and results of the thesis. It is a critical review of my work and the surrounding structures that make a thesis what it is. First, the validity of the collected data and analysis is discussed. This is done for all 5 steps of the analysis. Following this, a section containing the discussion of the analysis methods and results. The third section discusses the general reliability of the methods used and the findings from the 5 analysis methods. Last, recommendations for further work and research are given.

6.1 Validity

To validate the findings and results of the thesis, several methods have been used. First, the data collection is validated and discussed, followed by the five different analysis methods and their results.

6.1.1 Data collection

The collected data is validated by using triangulation and cross-referencing between the different data collection methods. The answers from the questionnaire given to Høglund are confirmed by the research the author of this thesis has done in the Høglund system and the semi-structured interviews. This is also true for the questionnaire given to Utkilen. In addition to this, an external company (Dolphin Drilling) from outside the Høglund system was given a questionnaire and semi-structured interviews. This was done to increase the reliability and validity of the finding from Utkilen. It also allows a more direct comparison between Utkilen and the external company.

To validate the diesel engine reliability data, it was compared with reliability data from OREDA (SINTEF 2002). Even though the reliability data used in this thesis contain some maintainable items not included in OREDA, where the data overlap, they show the same results. This gives credibility and thrust in the data used.

6.1.2 Analysis methods and results

To validate the methods used in the analysis, as well as the findings and results, Høglund was contacted as they are the main company of interest in this thesis. Høglund would also be the best choice for validation as they have extensive knowledge of their system and situation. Unfortunately, my contacts at Høglund did not have time to read through and validate my work and findings. To mitigate this shortcoming, I used my network and contacted a specialist (principal) engineer working for Equinor. He is named Mark Cowie and mainly works with artificial lift, but he has extensive knowledge in digitization, maturity analysis, and predictive maintenance. His background and experience make him a good substitute for Høglund. As Mr. Cowie does not have internal knowledge about Høglund and its systems, he could only validate my process and outcomes based on the information provided by me.

Overall he was satisfied by how the thesis was conducted and agreed with the analysis methods chosen for answering the research question. He thought that the needs and requirements and the SOS gave a good picture of Høglund‘s position in the marketplace. The maturity, gap, and SWOT analysis he thought showed a good view of how mature Høglund is today, the necessary improvements, and its relation to strategic planning and continuous improvement processes. Mr. Cowie emphasized that he also uses a prioritization list for implementations and enhancements. He thinks this is good practice. He also said that he usually divides his prioritization list into high, medium, and low, but A and B also work.

The main improvement he suggested was to include a time-frame on all the proposed improvements in the analysis. This will be helpful in the planning process as well as it will help to keep Høglund and its subcontractors accountable. The other suggestion from Mr. Cowie was to include a cost-benefit analysis of the improvements that were suggested. Both of these suggestions are appreciated, and something that I think would increase the usability of the thesis. Unfortunately, there is no time left to implement these suggestions. The semi-structured interview with Mr. Cowie was conducted on the 8Th of June. A transcript of the contents of the interview is attached in the appendix.

6.2 Analysis discussion

In this section, I will discuss the findings in all 5 analysis steps. I will also discuss the methods that are used and why they are the right ones to be used in this case. Each of the steps is discussed in the subsections below.

6.2.1 Systems of systems

The systems of systems (SOS) diagram shows that both Høglund and Utkilen are a part of the same industry and branch out into two separate paths at the enterprise level. The SOS diagram is there to show how Høglund can assist and offer their customers specific tasks. This is base upon Høglund developing their cloud service system to include predictive maintenance. As can be seen at the bottom level in the SOS, Høglund can offer both data collection and analysis of the data. Utkilen does not do this, and therefore it is a need that Høglund can fill for Utkilen.

6.2.2 Needs and requirement

The needs and requirement table show the needs of the essential stakeholder in relation to the predictive maintenance system that Høglund wants to include in their portfolio. This step is vital to know and show what is important to the stakeholder and the requirements and criteria to satisfy their needs. As can be seen in the needs and requirements table, it is performed with the cloud service that Høglund is offering in mind. This is so that when Høglund has a complete system including PdM, they can go in the table and see what needs they are satisfying for their stakeholders. All the stakeholders have safety as a common need that has to be satisfied. This means that one of the big selling points for Høglund could be that a PdM system could increase the safety of the operation.

When prioritizing what needs Høglund should focus on the most, Høglund should look at who is closest to them in the value chain. In this case, it will be Utkilen. The government and classification company are secondary stakeholders in the eyes of Høglund, as Utkilen is responsible for them in terms of the operation. Nevertheless, it should be taken into account when designing the system but as a secondary priority.

6.2.3 Maturity analysis

The maturity analysis is the first primary analysis method of this thesis. It was conducted to know precisely how mature Høglund is when it comes to the adaptation of PdM. As a secondary measure, and to understand how mature their customers are, Utkilen was also assessed. To increase the reliability of the findings at the customer side of the equation, a different company that could become a future customer of Høglund was also assessed.

The maturity analysis is the first step in the direction of knowing what needs to be done to get Høglund to a level of PdM 4.0.

As was found in the analysis, Høglund reached a maturity level of 3 out of 4. This clearly shows that they have more to work on before implementing more features into their system. Utkilen reached a maturity level of low 3 out of 4. This indicates that Utkilen has, even more, to gain from implementing PdM than Høglund. The same result was given to the additional company in the analysis that was Dolphin Drilling. The last measure in the maturity analysis was the combined maturity of Høglund and Utkilen. This resulted in a maturity level of between level 3 and 4 out of 4.

The overall maturity levels of the assessed companies show that they all have a lot to work on to reach a level of PdM 4.0. If Høglund implements PdM as a part of their portfolio in the cloud service, they could offer this to Utkilen and other customers. Doing so could increase the PdM level of both Høglund and its customers. What exactly needs to be done is discussed in the following subsection, gap analysis.

It is important to keep in mind that all the results of the maturity analysis are a product of subjective answers from the questionnaire. However, the people answering the questionnaire have senior positions in their companies and good knowledge of what they have and do not have. Therefore the results can be trusted as a general result, but not exact answers.

6.2.4 Gap analysis

As the maturity level and what functionalities are need for a full PdM implementation are known, the gap between them can be identified. This is done just for Høglund, as they are the company that would offer the PdM solutions to their customer.

What can be seen from the analysis is that Høglund lacks both in the hardware and software side in their pursuit of PdM 4.0. All their shortcomings have also been prioritized in sections A and B, where A is more important than B. In section, A of the prioritization list contains all the improvements that would create data. Section B contains all the analyses. Section A is prioritized over B because without the data and information, there is nothing to analyze.

When all the improvements have been identified, suggestions on how to improve them are given in the analysis. The improvement suggestions do not contain specific programs or hardware, rather general suggestions. This is because the software and hardware would differ a lot depending on whether Høglund chooses to develop the PdM system for themself or outsource it. As of now, Høglund is collaborating with a company called DIPAI. This company specializes in AI solutions and would most likely develop some of the software themselves in combination with already made solutions.

6.2.5 SWOT analysis

The SWOT analysis consists of the strengths, weaknesses, opportunities, and threats that Høglund is facing in regards to PdM. By making the SWOT analysis, light can be shed on the broader issues and opportunities that Høglund is facing. Both externally and internally. For the most part, the internal factors consist of what they have accomplished and what is left in their pursuit of PdM 4.0. The external factors consist more of the long-term opportunities and threats that Høglund is facing.

The internal factors in the SWOT have, for the most part, been covered in the maturity and gap analysis. What is most important in the SWOT is the external factors. The external section includes, for example, how the shipping industry is moving towards unmanned and autonomous ships and how other companies can beat Høglund to market and take their market share. The SWOT analysis does not contain all the strengths, weaknesses, opportunities, and threats that Høglund is facing but serves the purpose of shedding light on why Høglund should implement PdM more holistically.

6.3 General Reliability

The general reliability of the finding and analysis done in this thesis varies from section to section. The Systems of systems diagram, the needs and requirements table, and the SWOT analysis is specific to Høglund and could not be used for other companies without changes unless the companies are very similar to Høglund and have a cloud solution they want to develop further to include PdM.

The maturity analysis is general and could be fitted to any company on their way towards PdM 4.0. This said, it is in some cases a bit too general and is not picking up on important details. The reason it is this way is that it was developed by PWC and Mainnovation to work as a general framework in assessing companies' PdM maturity. To accommodate for the lack of detail, I have made specific questions in the questionnaire on the parts that were unclear. One example is that in the maturity framework, one of the criteria is if the companies have "multiple inspection points." These criteria do not include what inspection point and if the multiple inspection points describe different values. To gain more detail, I have asked what inspection points they have.

The gap analysis could also be used generally and fit any company in their pursuit towards PdM. The one thing to keep in mind is that the gap analysis used in this thesis depends on the maturity analysis to be conducted to get a picture of the company's current state. The future state is also derived from the maturity framework.

6.4 Further recommended research

Because of the limitations stated in chapter 1, section 5, the thesis and topic could still benefit from further research. There are, of course, many subtopics that can be further explored, the one I think is the most important is listed and shortly explained below.

1. Cost-benefit analysis

   A cost-benefit analysis would help to see what functions and features should be prioritized when implementing PdM. It would also help in clarifying the potential future gain of PdM for a company like Høglund.

2. Generalised method of hardware and software selection

   As this thesis does not include any technical suggestions, it could be a good idea to develop the gap analysis further to include this. If every criteria in the gap analysis are paired up with specific technical solutions, it could be used as a framework when selecting the necessary hardware and software.

3. Research in the other areas of ship maintenance

   For delimiting purposes, this thesis has focused on the main engine as the asset of interest. There are many other areas onboard a ship that need maintenance and that could benefit from PdM. For example, the propulsion, gearbox, auxiliary boilers, and fuel pump, to mention some.

Chapter 7

Conclusion

The purpose of this thesis was to answer the research question: How could Høglund Marine Solutions's cloud service reach a maturity level of PdM 4.0, so it can be used for predictive maintenance in the shipping industry?

The answer for this question based on the conducted case study is as follows:

1. Cloud service providers like Høglund has to build customized maturity model, as the general maturity models (e.g. the one developed by PwC) have limitations when it comes to detailed specifications.

2. The maturity model for cyber-physical systems requires considering both the cloud service provider and their customer. It is clear from the results that a combined maturity model provides higher maturity levels.

3. Cloud service providers shall focus on full sensorization and data collection to support the analytics of interest. This should be based on the prioritization table that can be derived from the Gap analysis.

4. Cloud service providers shall consider Gap and SWOT analysis to connect the maturity studies and findings with strategic planning.

5. Maturity studies shall be utilized to support the decision-making process and it shall be part of the continuous improvement processes.

Below, the conclusions from each analysis method and what was learned from them are given and explained. Following the analysis method conclusions, a general conclusion of the state of Høglund is given.

- Systems of systems (SOS) diagram & Needs and requirements table

  The SOS and Needs and Requirements table was conducted to gain an overview of the position Høglund has in the shipping industry and the needs of the most critical stakeholders.

What was learned from the systems of systems diagram was that Høglund is a part of the same industry but at a different branch on the enterprise level from their customers. This puts Høglund in a position to develop their cloud service further to include PdM and offer this to their customers. As the SOS show, the Høglund customers, for the most part, are concerned about the operation of the ships, and Høglund would therefore be filling a gap in their operation by offering them analysis and PdM tools.

The needs and requirement table show that Høglund's customers are not the only stakeholders they need to consider. For example, as the customers are ship owners and operators, they need to relate to both the government and the classification company. This is important to keep in mind when developing the cloud service systems further.

- Maturity & Gap analysis

  The most important results for answering the research question came from the maturity and gap analysis. What the maturity analysis showed was that Høglund is not collecting the correct data for predictive maintenance. They are mostly collecting pressure and temperature data that are difficult to use in a PdM context. This is due to the rapid changes that occur in this type of data. The maturity analysis also uncovered that Høglund is not conducting any analysis on the data they are collecting. They do not use any statistical or condition monitoring software at the moment.

  The gap analysis shows what needs to be improved and further developed in the cloud service system for Høglund to reach a level of PdM 4.0. The first that needs to happen to get further in the pursuit of PdM is that Høglund needs to collect the right types of data. Vibration and oil debris sensors are suggestions on what would give them data that can be analyzed in a long-term perspective and be useful for PdM. Digital maintenance history and more digital environmental data are also crucial for Høglund to obtain the necessary data for analysis. When all this data is present in the Høglund cloud service system, the data analysis can start. This includes trend analysis, the use of statistical software and advanced decision support, as well as condition monitoring software. To accomplish this, Høglund needs to develop its platform further to accommodate for even more data and hire a data scientist to take on the work.

- SWOT analysis

  The most significant takeaway from the SWOT analysis is the external components that affect Høglund as a company. Both the opportunities and threats they are up against. By including PdM in Høglund's cloud service, they open up for new customers and create new needs for their existing customers. It also shows that by failing to implement PdM as a part of their portfolio, they risk losing some of their existing customers to other companies, and they will not be mature enough to contribute to the next technological development in the shipping industry. Like for example, autonomous ships.

All in all, Høglund has a lot of the necessary infrastructure to offer PdM to their customers. However, they are underdeveloped in certain areas, like the data they collect and the missing data analysis. The overall maturity level Høglund obtain at the moment is 3 out of 4. By allocating resources to develop their cloud service system further, they will most likely reach a level 4 if they want to.

Bibliography

Adam Henshall (2019), 'What are Maturity Models in Business? (Capability Maturity Model, AIMM, and More)'.
URL: *https://www.process.st/maturity-model/*

Alan Faisandier, Garry Roedler (2021), 'Stakeholder Needs and Requirements'.
URL: *https://www.sebokwiki.org/wiki/Stakeholder*$_N$*eeds*$_a$*nd*$_R$*equirements*

Albliwi, S., Antony, J. & Arshed, N. (2014), 'Critical literature review on maturity models for business process excellence', *2014 IEEE International Conference on Industrial Engineering and Engineering Management* pp. 79–83.

Anyoha, R. (2017), 'The History of Artificial Intelligence'.
URL: *https://sitn.hms.harvard.edu/flash/2017/history-artificial-intelligence/*

Ben-Daya, M. M. (2016), *Introduction to maintenance engineering : modeling, optimization, and management*, Wiley, Chichester, England.

Carlsen, A. (2020), 'A self-assessment model for intelligent predictive maintenance analytics: An update of the analyses module in the maintenance baseline study'.

Club, T. S. (2015), 'Main engine damage'. [Online]; Accessed February 08, 2021.
URL: *https://www.swedishclub.com/media*$_u$*pload/files/Publications/Loss%20 Prevention/Main%20Engine%20damage%202015%20The%20Swedish%20Club.pdf*

Deighton, M. (2016), *Facility Integrity Management: Effective Principles and Practices for the Oil, Gas and Petrochemical Industries, [Page 97 - 105]*, Elsevier Science Technology, Oxford.

Eda Kavlakoglu (2020), 'AI vs. Machine Learning vs. Deep Learning vs. Neural Networks: What's the Difference?'.
URL: *https://www.ibm.com/cloud/blog/ai-vs-machine-learning-vs-deep-learning-vs-neural-networks*

Expert.ai Team (2020), 'What is Machine Learning? A Definition.'.
URL: *https://www.expert.ai/blog/machine-learning-definition/*

Fedele, L. (2011), *Methodologies and Techniques for Advanced Maintenance*, Springer London, Limited, London.

Flovik, V. (2019), 'Machine learning for anomaly detection and condition monitoring'. [Online]; Accessed June 08, 2021.
URL: *https://towardsdatascience.com/machine-learning-for-anomaly-detection-and-condition-monitoring-d4614e7de770*

Frost, J. (2017), 'When should i use regression analysis?'.
URL: *https://statisticsbyjim.com/regression/when-use-regression-analysis/*

Gjoko Muratovski (2020), 'Industry 4.0 Is Already Here, But Are You Ready?'.
URL: *https://www.forbes.com/sites/forbesagencycouncil/2020/09/08/industry-40-is-already-here-but-are-you-ready/?sh=186b373044b5*

IBM Cloud Education (2020), 'Machine Learning'.
URL: *https://www.ibm.com/cloud/learn/machine-learning*

IDC, D. R. (2018), 'The digitization of the world - data age 2025'. [Online]; Accessed January 28, 2021.
URL: *https://www.seagate.com/gb/en/our-story/data-age-2025/*

iED Team (2019), 'The 4 industrial revolutions'.
URL: *https://ied.eu/project-updates/the-4-industrial-revolutions/*

ISO (2009), 'Iso 10816-3:2009, mechanical vibration', *ISO* .

Jake Frankenfield (2020), 'Cloud Computing'.
URL: *https://www.investopedia.com/terms/c/cloud-computing.asp*

Jason Fernando (2021), 'Stakeholder'.
URL: *https://www.investopedia.com/terms/s/stakeholder.asp*

Kollmorgen (n.d.), 'What is the difference between mtbf and mttf?'. [Online]; Accessed March 08, 2021.
URL: *https://www.kollmorgen.com/en-us/developer-network/what-difference-between-mtbf-and-mttf-0/*

Larry Hardesty (2017), 'Explained: Neural networks'.
URL: *https://news.mit.edu/2017/explained-neural-networks-deep-learning-0414*

Marr, B. (2018), 'What is industry 4.0?'.
URL: *https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/?sh=79ea2b909788*

Martin Luenendonk (2019), 'Industry 4.0: Definition, Design Principles, Challenges, and the Future of Employment'.
URL: *https://www.cleverism.com/industry-4-0/*

Michel Mulders, M. H. (2018), 'Predictive maintenance 4.0. beyond the hype:pdm 4.0 delivers results'. [Online]; Accessed January 29, 2021.
URL: *https://www.mainnovation.com/wp-content/uploads/tmp/6397245268d8d3711c88cda0b4585ab*

Naveen Kumar, J. K. (2014), 'Efficiency 4.0 for industry 4.0', *Indian institute of technology Delhi* .

Pierre Dersin, Alstom Transport (2014), 'Stakeholder'.
URL: *https://rs.ieee.org/technical-activities/technical-committees /systems-of-systems.html*

Press, G. (2020), '6 predictions about data in 2020 and the coming decade'. [Online]; Accessed January 28, 2021.
URL: *https://www.forbes.com/sites/gilpress/2020/01/06/6-predictions-about-data-in-2020-and-the-coming-decade/?sh=5a59e5b54fc3*

Qureshi, M. A. (2020), *Valve Health Identification Using Sensors and Machine Learning Methods, [Page 46]*, Ireland's centre for applied AI, Dublin.

Sai Vennam (2020), 'Cloud Computing'.
URL: *https://www.ibm.com/cloud/learn/cloud-computing*

SINTEF (2002), *Offshore reliability data handbook*, ODERA Participants.
URL: *https://www.nri.ac.ir/Portals/0/images/Technology/OandM/document/OREDA.pdf*

Solutions, H. M. (n.d.), 'Ship performance monitor (spm)?'. [Online]; Accessed MARCH 10, 2021.
URL: *https://hoglund.no/solutions/marine-automation/ship-performance-monitor-spm*

Somayya Madakam, R. Ramaswamy, S. T. (2015), 'Internet of Things (IoT): A Literature Review', *Journal of Computer and Communications* .

Statista (2019), 'Number of ships in the world merchant fleet as of january 1, 2019, by type'. [Online]; Accessed February 08, 2021.
URL: *https://www.statista.com/statistics/264024/number-of-merchant-ships-worldwide-by-type/*

Steve Nixon, Ryan Weichel, K. R. J. K. (2018), 'A Machine Learning Approach to Diesel Engine Health Prognostics using Engine Controller Data', *Applied Research Laboratory* .

Tidemann, S. (2020), ‘Kunstig intelligens’, *Store Norske Leksikon* .

Ullah, M. I. (2014), ‘Component of time series data’.
URL: *https://itfeature.com/time-series-analysis-and-forecasting/component-of-time-series-data*

Utkilen (n.d.).
URL: *http://www-cs-faculty.stanford.edu/ uno/abcde.html*

Vailshery, L. S. (2021), ‘Iot connected devices worldwide 2030’.
URL: *https://www.statista.com/statistics/802690/worldwide-connected-devices-by-access-technology/*

Will Kenton (2020), ‘Gap Analysis)’.
URL: *https://www.investopedia.com/terms/g/gap-analysis.asp*

Will Kenton (2021), ‘Strength, Weakness, Opportunity, and Threat (SWOT) Analysis)’.
URL: *https://www.investopedia.com/terms/s/swot.asp*

Yin, R. (2013), *Case Study Research: Design and Methods*, SAGE Publications.
URL: *https://books.google.no/books?id=AjV1AwAAQBAJ*

Appendix A

Appendix

A.1 Høglund's questionnaire answers

Predictive Maintenance (PdM) Maturity Assessment for Høglund`s Cloud Service

The questionnaire consist of 15 questing divided into 4 parts. The purpose of the questionnaire is to help assess the maturity of Høglund`s cloud service in terms of PdM readiness.

Part 1: Background information

1: Your name:

Aleksander Beckmann

2: Your Position:

Sales Manager - Digital Solutions

3: Company name:

Høglund Marine Solutions

4: What do you see as the most important aspect of the service that Høglund deliver to its customers regarding the cloud service?

Data Presentation , Data analyzes

5: Is Høglund as a company willing to develop its cloud service to include predictive maintenance solutions in the future?

Yes. We do have a parter with DIPAI at the moment

Part 2: Performance measures

How the data is used and analysed

6: Is trend analysis done on the collected data?

- ○ Yes
- ○ No
- ◉ Andre: It will be available in the upcomming new software platform

7: Does the data points get monitored by condition monitoring software?

- ○ Yes
- ◉ No
- ○ Andre:

8: Is predictions of the future state of the asset done by experts or by the use of statistical software?

- ○ Experts
- ○ Statistical Software
- ○ Both
- ○ None
- ◉ Andre: It will be a potential product through parters

What IT infrastructure are in place?

9: Which information and communication platform/software (ICT) is used by your company? (eg ERP, CMMS, SACA etc)

10: Is condition monitoring data classified and stored accordingly?

- (x) Yes
- ( ) No
- ( ) Andre:

11: If yes on question 10; what classification requirements are used to organize the data?

- [x] Asset tag no
- [ ] Data format (e.g vibration, temperature, pressure etc)
- [x] Time
- [x] Date
- [ ] Andre:

12: If you have multiple ICT systems; Are they connected and "talk" to each other?

- ( ) Yes
- (x) No
- ( ) Andre:

13: How is the data transmitted? (e.g Wifi, fiber optics, satellite)

HTTPS through satelite

Part 4: Organization

What resources are available

14: Is there a willingness internally for implementing predictive maintenance for your assets?

- (x) Yes
- ( ) No
- ( ) Andre:

15: What of the following personnel do you have access to internally for maintenance analytics?

- [ ] Experienced craftsmen
- [ ] Trained inspectors
- [x] Reliability engineers
- [ ] Data scientists
- [ ] Andre:

A.2 Utkilen's questionnaire answers

Predictive Maintenance (PdM) Maturity Assessment

The questionnaire consist of 32 questing divided into 6 parts. The purpose of the questionnaire is to help assess the maturity of the firm in terms of PdM readiness.

Part 1: Background information

1: Your name

Sven Rolfsen

2: Your position

Technical Manager

3: Company name

Utkilen

4: How is maintenance done today for your assets?

- [ ] Corrective, reactive
- [x] Preventive
- [x] Predictive

5: What is your strongest motivator for implementing predictive maintenance?

- [x] Increased uptime
- [x] Increased lifespan of asset
- [x] Reduction of operation cost
- [ ] Classification
- [ ] Do not think it is useful
- [ ] Andre:

6: What is the most important aspect of the cloud service that Høglund provides today for you?

Easy accessible data.

Part 2: Process:

How the maintenance data is collected

7: Is the assets inspections periodic or continuous? (Assets could for example be main engine, diesel generator etc)

- (•) Periodic
- ( ) Continuous

8: Is the inspections done remotely or in person by an operator?

- (selected) A: Remote inspections
- B: In person inspections
- C: Both

9: How much of your data is collected using sensors?

- <20% :None
- (selected) >20% :Few
- >40% :Some
- >60% :Most
- >80% : Almost all
- 100% :All

10: Is the inspection done using a checklists?

- yes
- (selected) No

11: Is the maintenance recorded analog or digital?

- analog
- (selected) digital

Part 3: Content

What data is collected

12: Is the condition data recorded digitally or on paper?

- (selected) Digital
- Paper
- Both

13: If condition data is collected, what sort of sensors are installed on your asset?

- [x] Temperature
- [x] Preassure
- [ ] Oil debris data
- [x] Vibration
- [ ] Acoustics
- [ ] Other

14: Is the condition data recorded by a single or multiple inspection points?

- Single
- (selected) Multiple

15: Is environmental condition data collected and stored digitally?

- Yes
- (selected) No

16: Is historical maintenance data collected and stored digitally?

- (selected) Yes
- No

Part 4: Performance measurement

How the data is used and analysed

17: Is there a visual norm verification in regards to the asset?

- (selected) yes
- No

18: Is the norm verification automatic?

- yes
- (selected) no

19: Is the trend analysis done digitally or on paper?

- (selected) digitally
- paper
- no trend analysis is done

20: Does the data points get monitored by condition monitoring software?

- Yes
- (selected) No

21: Is predictions of the future state of the asset done by experts or by the use of statistical software?

- (selected) Experts
- Statistical software
- Both
- Andre: ____

Part 5: IT

What IT infrastructure are in place?

22: Which information and communication platform/software (ICT) is used by your company? (eg ERP, CMMS, SACA etc)

?

23: Is condition monitoring data automatically stored?

- (●) yes
- ( ) no

24: If yes on question 23; Where is condition monitoring data stored?

Many places

25: Is condition monitoring data classified and stored accordingly?

- (●) yes
- ( ) no

26: If yes on question 25; what classification requirements are used to organize the data?

- [x] Asset tag number
- [x] Data format (e.g vibration, temperature, pressure etc)
- [ ] Time
- [ ] Date
- [ ] Andre:

27: If you have multiple ICT systems; Are they connected and "talk" to each other?

- ( ) Yes
- (●) No
- ( ) Andre:

28: How is the data transmitted? (e.g Wifi, fiber optics, satellite)

Satellite

29: Who receive the data?

- ( ) Internal system on operation site
- ( ) Internal system onshore
- (●) External third part receive the data

30: If third part receive condition data; Specify who they are and what they do with the data

Info Marine, Gdansk. Analyze vibration data

Part 6: Organization

What resources are available

31: Is there a willingness internally for implementing predictive maintenance for your assets?

- [x] yes
- [ ] No
- [ ] Andre:

32: What of the following personnel do you have access to internally for maintenance analytics?

- [x] Experienced craftsmen
- [x] Trained inspectors
- [ ] Reliability engineers
- [ ] Data scientists
- [ ] Andre:

A.3 Dolphin Drilling‘s questionnaire answers

Predictive Maintenance (PdM) Maturity Assessment

The questionnaire consist of 32 questing divided into 6 parts. The purpose of the questionnaire is to help assess the maturity of the firm in terms of PdM readiness.

Part 1: Background information

1: Your name

Ivar Brekke

2: Your position

Technical section leader (Chief engineer)

3: Company name

Dolphin Drilling

4: How is maintenance done today for your assets?

- [x] Corrective, reactive
- [x] Preventive
- [ ] Predictive

5: What is your strongest motivator for implementing predictive maintenance?

- [x] Increased uptime
- [x] Increased lifespan of asset
- [x] Reduction of operation cost
- [x] Classification
- [ ] Do not think it is useful
- [ ] Andre:

6: What is the most important aspect of the cloud service that Høglund provides today for you?

Part 2: Process:

How the maintenance data is collected

7: Is the assets inspections periodic or continuous? (Assets could for example be main engine, diesel generator etc)

- (x) Periodic
- ( ) Continuous

8: Is the inspections done remotely or in person by an operator?

- ( ) A: Remote inspections
- ( ) B: In person inspections
- (x) C: Both

9: How much of your data is collected using sensors?

- ( ) <20% :None
- ( ) >20% :Few
- ( ) >40% :Some
- ( ) >60% :Most
- ( ) >80% : Almost all
- ( ) 100% :All

10: Is the inspection done using a checklists?

- (x) yes
- ( ) No

11: Is the maintenance recorded analog or digital?

- ( ) analog
- (x) digital

Part 3: Content

What data is collected

12: Is the condition data recorded digitally or on paper?

- (x) Digital
- ( ) Paper
- ( ) Both

13: If condition data is collected, what sort of sensors are installed on your asset?

- [x] Temperature
- [x] Preassure
- [ ] Oil debris data
- [ ] Vibration
- [ ] Acoustics
- [x] Other

14: Is the condition data recorded by a single or multiple inspection points?

- ( ) Single
- (x) Multiple

15: Is environmental condition data collected and stored digitally?

- ( ) Yes
- (x) No

16: Is historical maintenance data collected and stored digitally?

- (x) Yes
- ( ) No

Part 4: Performance measurement

How the data is used and analysed

17: Is there a visual norm verification in regards to the asset?

- (x) yes
- ( ) No

18: Is the norm verification automatic?

- (x) yes
- ( ) no

19: Is the trend analysis done digitally or on paper?

- ( ) digitally
- ( ) paper
- (x) no trend analysis is done

20: Does the data points get monitored by condition monitoring software?

- ( ) Yes
- (x) No

21: Is predictions of the future state of the asset done by experts or by the use of statistical software?

- (x) Experts
- ( ) Statistical software
- ( ) Both
- ( ) Andre: ____

Part 5: IT

What IT infrastructure are in place?

22: Which information and communication platform/software (ICT) is used by your company? (eg ERP, CMMS, SACA etc)

SAP, SCADA

23: Is condition monitoring data automatically stored?

- ( ) yes
- (•) no

24: If yes on question 23; Where is condition monitoring data stored?

25: Is condition monitoring data classified and stored accordingly?

- ( ) yes
- ( ) no

26: If yes on question 25; what classification requirements are used to organize the data?

- [ ] Asset tag number
- [ ] Data format (e.g vibration, temperature, pressure etc)
- [ ] Time
- [ ] Date
- [ ] Andre:

31: Is there a willingness internally for implementing predictive maintenance for your assets?

- [x] yes
- [ ] No
- [ ] Andre:

32: What of the following personnel do you have access to internally for maintenance analytics?

- [x] Experienced craftsmen
- [x] Trained inspectors
- [ ] Reliability engineers
- [ ] Data scientists
- [ ] Andre:

27: If you have multiple ICT systems; Are they connected and "talk" to each other?

- ( ) Yes
- (•) No
- ( ) Andre:

28: How is the data transmitted? (e.g Wifi, fiber optics, satellite)

No transmission to onshore, cabling to on-ship computer

29: Who receive the data?

- (•) Internal system on operation site
- ( ) Internal system onshore
- ( ) External third part receive the data

30: If third part receive condition data; Specify who they are and what they do with the data

Part 6: Organization

What resources are available

A.4 Semi-Structured Validity Interview

Semi- structured Validity interview:

Conducted by Oscar Holmås, 08.06.2021.

The interview is with: Mark Cowie, Equinor, Specialist, Artificial lift, Experienced with digitalization and PdM

- Overall satisfied with the analysis methods and how the analysis was conducted.

- The scorecard is understandable and make sense.

- Pleased with the gap analysis and prioritization list. Thinks this is helpful when improvements shall be made. He uses the same system in Equinor, but instead of an A and B lists he makes it into a Low, Medium, and High prioritization.

- The SWOT analysis clearly show how the maturity of the company is a part of the bigger picture and how it can be helpful to use in strategic planning and for continuous improvement purposes.

- Improvements and enhancements that that could have been made if resources and time was not an issue:

    - A time frame of all the improvements that are suggested in the thesis

    - A cost benefit analysis of implementing PdM and the improvements suggested in the thesis.