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Abstract

Hydro is a fully integrated aluminium company with employees in countries worldwide. Maintaining equipment that is being used in the production of aluminium is an important and complex task. There are many critical operations in the production process, and the need for functioning equipment with optimal quality is essential.

The maintenance decisions related to repair specific failed components or replace the whole equipment, are today made based on information about the condition of one component and not based on the condition of the whole system. If fact, the managers at the case company (Hydro Aluminium Karmøy) feel that the accumulated repair costs of several components (e.g. pump, motor) within one subsystem (e.g. hydraulic system) might exceed the price of replacing the subsystem or even the whole system (e.g. tapping carriage). However, it is hard to determine whether and when the failed components should be repaired or if the whole subsystem/system should be replaced.

The purpose of this master thesis is to support the repair vs replace decision making process with a predictive and illustrative model, that will help to anticipate and visualise a potential cost-effective maintenance policy that takes the whole system into consideration when maintenance decisions are to be made.

In order to do this, a critical system in aluminium production is selected as a case study and its associated maintenance and failure data is studied. The first step is to identify a critical subsystem and components within the selected system, that are further analysed. The maintenance events and the associated costs of the selected components is established to draw up the maintenance event timeline and use this as inputs for the developed system dynamic model, with the help of a simulation program called Vensim. The program is used to simulate the accumulated maintenance lifetime cost with both a local (repair cost of individual components) and a global (accumulated repair cost of all components) focus, and then comparing it with the cost of buying a new system (replacement cost). The simulated dynamic model would help the case company to make better decisions about e.g. repair vs replace.

First, the predictive model proved that the accumulated cost for maintaining a few components over a short period of time, would approximately reach the cost of replacing the whole subsystem. This supports the fact that a global perspective would be a better maintenance policy, than a local. Second, the predictive model illustrates how to utilize the collected maintenance data in order to learn and perform predictive analytics. This model emphasis the need to have integrated data collection system so that required inputs can be fed into the predictive model. Third, this study show that data quality is significant to predict potential scenarios and support the decision-making process regarding equipment replacement i.e. repair vs replace. High quality data increase the reliability and validity of using this data to learn and predict future patterns and maintenance strategies. In summary, the case study could show the benefit of using predictive simulation model to visualise the potential accumulated maintenance cost at component, subsystem and system levels.

Acknowledgements

I want to express my gratitude to my supervisor and professor at the University of Stavanger, Idriss El-Thalji for his support and guidance throughout the work of my master thesis. His expertise within operation and maintenance has been a valuable resource.

I also want to thank the maintenance department at Hydro Aluminium Karmøy, for giving me the opportunity to write my master thesis within a relevant subject. I am especially grateful to my supervisor at Hydro, Leif Tore Larsen for his contribution, help and guidance.

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List of abbreviations

CM	Corrective Maintenance
CMMS	Computerized Maintenance Management System
HAK	Hydro Aluminium Karmøy
LORA	Level of Repair Analysis
PLE	Personal Learning Edition
PM	Precautionary Maintenance
SAP	Systems, Applications and Products (company)
UIS	University in Stavanger

List of terminology

Expression	**Meaning**	**Reference**
Local level	Considering one component at the time	Hydro
Global level	Considering the whole (sub)system at once	Hydro
System	The equipment in its entirety	Hydro
Subsystem	The equipment is divided into several subsystems, e.g. hydraulic system, electrical system etc.	Hydro
Component	The subsystem is built up of many components, e.g. engine, pump, hose etc.	Hydro

1 Introduction

1.1 Problem background

The motivation behind this project is to look at the opportunity to optimise the policy for replacement and maintenance regarding components and systems in the aluminium production industry. The thesis aims to explore different maintenance policies, meaning what lies to ground when decisions about maintenance are made.

Today the maintenance department at Hydro Aluminium Karmøy (HAK) make decisions about the need for replacement and maintenance based on the condition of the system on a local level. This means that in situations where corrective maintenance is needed, they only take one component in the system into account when making a decision about which actions to take. There are need for a policy that allows the maintenance department at HAK to make decisions about replacement and maintenance based on the condition of the whole system, in other words - on a global level. Instead of only looking at only one component at the time, the subsystem or even the whole system should be evaluated. The lack of this opportunity is not a critical problem, but there are room for improvement. Situations where components are replaced or maintained and a short time later the whole system or subsystem needs replacement due to shut down, is situations that most definitely should (and in many cases could) be avoided.

This optimization or decision making problem is well known in the maintenance literature as ‘repair vs replace’ (1). The “Repair vs replace” problem is related to a situation where the industrial manager try to decide whether to repair the failed component or replace the whole equipment. Therefore Jardine (1) considered this problem under a group of “equipment replacement decision”. However, in order to determine the optimal interval of when to repair or replace, the forecasted/predicted accumulated repair cost is required. Therefore, the purpose of this thesis is to propose a model that help us to learn the maintenance event patterns (frequency and cost) based on historical failure and maintenance records and then simulate these patterns to predict the potential repair cost of each component within the whole system.

Logging of information and data regarding operation and maintenance, replacement and repair is also an important aspect of the process. If the data is not reported the correct way, it can be difficult to get right information about the assets condition patterns, health and value. Without this information, the most effective and optimal decisions about the future care of the system might be hard to make.

1.2 Problem formulation

Maintaining equipment that is being used in the production of aluminium is an important and complex task. There are many critical operations in the production process, and the need for functioning equipment with optimal quality is a must. The maintenance department at HAK are responsible for keeping the equipment on a functional level at all times, allowing the aluminium production to proceed on a daily basis. They must plan, make, and follow a good and optimal maintenance policy, evaluate different situations and make sure the maintenance is done in the most efficient way based on the given situation. They must also evaluate the condition of the equipment and consider the need for repair or replacement of components, subsystems and systems.

Hydro operates with both corrective and preventive maintenance, more about this in *chapter 0*

Maintenance, but as mentioned; today the decisions that are made about repair or replace, are mainly made on information about the condition, health and value of one component and not based on the whole system. Not taking the whole systems conditions into consideration will not always be sufficient and wont necessary give the optimal maintenance-solution. A better, more optimized and cost-effective maintenance policy that instead takes the whole system into consideration is there for desirable.

However, to develop an optimized maintenance policy and a program or a model that gives a complete understanding of the equipment's condition can be challenging. From risk and complications regarding the technology and program development, making it user friendly, providing data that actually helps with the question about repair or replace, and the fact that personnel may need to change some of their routines, are all situations that can be a challenge in this process.

1.3 Research question and project objective

1.3.1 Research question

> *How can a global perspective of specific critical assets be analysed and visualized to support equipment replacement decisions i.e. repair vs replace?*

It is this question the master theses will try to answer, to the best of the authors ability.

1.3.2 Hypothesis

Based on conversations with head of maintenance department at HAK, Leif Tore Larsen, discussing how HAK's maintenance policy on complex systems is handled today, related problems and potential improvement points, the subject for the thesis were selected: The effect of Maintenance optimization. After digging deeper into today’s situation and related problems, a hypothesis was formulated.

The hypothesis is that if HAK’s corrective maintenance switch from having a local focus to a global maintenance policy it would be easier to make the right decisions regarding replacement or repair of components vs replacement of the whole system or even subsystem. Switching to a global perspective could also result in a cut of costs in the long run, as well as it would contribute to getting a better overview of the condition and asset value to the whole system, not only information about one component at a time.

However, there may be other conditions than the cost that will influence the question about repair or replace, but those will not be highlighted in this master thesis.

1.3.3 Project objective

The objective of this thesis is to investigate potential improvement of the maintenance policy at HAK, evaluate a new tool for decision making regarding repair and replacement in critical systems in the aluminium production process, as well as evaluate how potential changes will influence the maintenance operations at HAK.

The motivation behind the project, and the reason for why this case study has been commenced, is to explore the opportunity to use other maintenance policies than the one(s) being used at HAK today. As mentioned, today the maintenance department at HAK make decisions about the condition and need for maintenance on a local level. This thesis will look at the possibility to change the perspective and evaluate several components, a subsystem or a complete system when making decisions about repair or replacement.

1.4 Methodology

The research method used in this master thesis is a 'Single Case Study', with a deductive approach using quantitative methods to answer the research question and hypothesis in the study.

A deductive approach focuses on developing a hypothesis based on existing theory and conditions, and then design a research strategy to test the formulated hypothesis before a final confirmation or rejection of the hypothesis is made (2). Figure 1 illustrates the deductive approach.

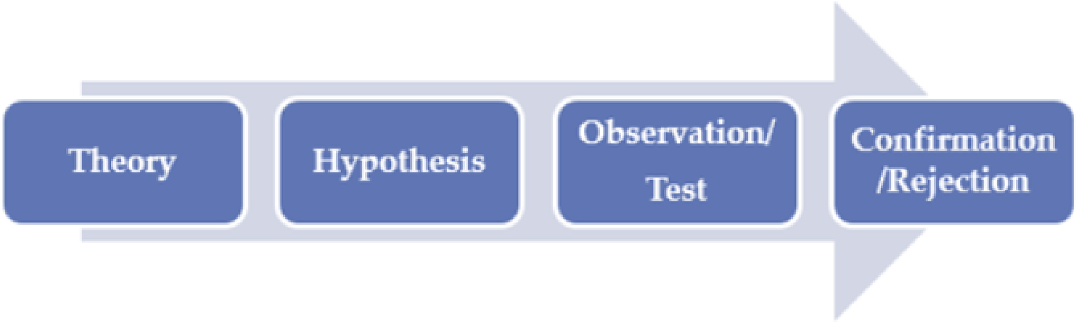


Figure 1: Illustration of deductive approach

(3)

According to John Dudovskiy (3) there are generally five steps that are followed when using a deductive approach. These steps are making a hypothesis from theory, formulating the hypothesis, testing the hypothesis, examining the outcome of the test and confirm or reject the theory and then at last modify the theory in cases where the hypothesis where not confirmed.

This case study follows this method in some ways. A hypothesis was made based on existing theory and current conditions including conversations with head of maintenance at HAK about current states and desired outcomes. Then data was collected, reviewed and analysed before making a simulation and a dynamic model which would confirm of reject the hypothesis. In addition to this there were made some notes about the reporting system for maintenance actions used at HAK.

1.5 Project scope and delimitation

1.5.1 Scope:

The scope of this thesis is to evaluate the need for a change in maintenance policy, from a local and component-based perspective to a global and whole-system perspective. The thesis will look into if there is need for a new decision-making method, based on the lifetime cost of maintaining components vs the cost of replacing the whole system or subsystem. The thesis is going to establish an overview of the maintenance policy used today, the corresponding challenges and what could be improved by changing the maintenance policy. There will also be developed a model to help with making the decisions about repair or replace. This model will however only be a basic model with a simplified simulation to demonstrate how it could be possible to use this model in decision making regarding maintenance operations.

To be able to answer these questions and make the model, there will be used existing theory, in addition to going deeper into one specific case and look at its corresponding maintenance data. Tapping carriages, that are used in aluminium production, will be used as an example of a critical system in this case study.

1.5.2 Delimitations

Several delimitations were purposefully taken to ensure that the planned analysis and the demonstrative case was performed in a reliable and valid manner within the limited time (5 months) and resources (existing database at the case company), as follows:

- The case study has purposefully delimited to consider only one critical system from the aluminium production, due to the restriction of time and not making the case too comprehensive.
- The case study was purposefully delimited further for only one sub system within the main system where two critical components were analysed, due to the restriction of time and required efforts to gather, trace, request completeness/explanations of the failure data and cost data and extract the maintenance event timeline.
- The modelled system within the case study was purposefully simulated based on certain parameters (historical features i.e. failure frequency, cost of consequences) and time span (2010-2017).
- The thesis uses a tapping carriage as a case study, since the industrial manager at the case company think this might be a relevant system to demonstrate the planned model and to answer the thesis objective.
- The case study does not take the future cost of maintaining the replaced equipment into consideration, when answering the hypothesis and research question, about local vs global perspective and repair vs replace.
- The case study has purposefully not laid weight on the impact of the equipment’s production stop due to maintenance, because this is not critical in this specific case (4).

1.6 Thesis outline

This thesis is divided into seven chapters. First the introduction of the case study in chapter 1, followed by the theory and literature review in chapter 2, which includes all the information that is relevant to understand the research in this thesis. Chapter 2 includes theory about aluminium and how it is made and used, including theory about different maintenance strategies and different programs used during the thesis. Chapter 3 explains how the thesis will develop, the research methodology and the model structure, and chapter 4 includes all the data that are collected in order to complete this master thesis. Chapter 5 shows the data analysis done step by step and explains how the methodology from chapter 3 is done. The result is presented and discussed in chapter 6, followed by chapter 7 with a conclusion and recommendation for further development.

2 Theory and literature review

This chapter will present relevant theory around the topics that will be mentioned during this master thesis and are relevant for the topic.

2.1 Why aluminium?

The greenhouse effect is a natural process that heats our atmosphere and make it possible for humans to live on the earth. Without it the average temperature would be - 18 degrees Celsius instead of + 15 degrees Celsius which the average temperature is today, according to Ungenergi (5). Some of the gasses that are present in the atmosphere are greenhouse gasses, and they work the same way as a greenhouse. They let the solar energy in, but they stop the heat from letting back out to space, this way the earth stays warm (5).
However, if the amount of greenhouse gasses in the atmosphere becomes too big, there will be serious consequences for life on earth. Emission of greenhouse gasses caused by humans, will contribute to an increase in greenhouse gases in the atmosphere, and a rise of the average temperature on earth. Therefor it is very important to limit these emissions, and that all countries work together against the same goal - reduce emissions of greenhouse gases (5).

There are many measures that can be done to reduce the emission of greenhouse gases, such as renewable energy sources, better environmental policy and development within environmental technology (5). More climate-friendly production processes, recycling and use of renewable energy are measurer that Hydro have a high focus on in their aluminium production. Aluminium is a very important and valuable material due to its excellent properties such as strength, durability, flexibility, lightness, non-corrosiveness, conductivity and recyclability. Because of these excellent properties aluminium play a central role in solving the sustainable challenge in the world, and when meeting the expectations of an improving quality of life (6).

Because of aluminium's central position towards a sustainable future it is important with high focus on measures to reduce emission of greenhouse gases. Although aluminium is recyclable, many of the products have so long lifetime that the volume of aluminium available for recovery is relatively low as the metal is still being used (7). Therefore, to be able to meet the global demand for aluminium in the coming years, there need to be a combination of both recycling and production of new primary aluminium. This is illustrated in Figure 2, made by European Aluminium (7).

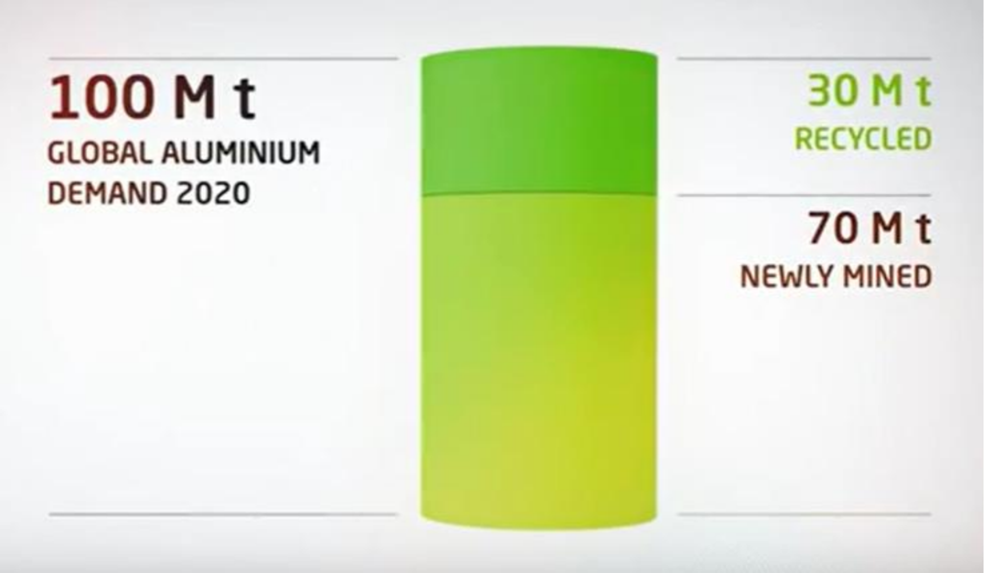


Figure 2: Distribution between primary and recycled aluminium

Source: (7)

European Aluminium describes the world development this way: “We are moving into a low carbon economy. New business models, IT innovation, decentralized governance, and energy efficiency are some of the key words that are re-defining our societies. Aluminium is playing a fundamental role to drive this transformation thanks to what we call “Aluminium Effect” (6).”

In January 2018, Hydro started a pilot plant in Karmøy with a new technology delivering the most climate and energy-efficient aluminium production in the world. This plant will produce 75 000 tonnes aluminium, be 15 % more energy efficient compared to the world average and give the world’s lowest CO2 footprint (8). This new technology developed by Hydro's technology centres in Årdal and Porsgrunn in Norway and Neuss in Germany, is the next generation in electrolysis technology and it will reduce energy consumptions and emissions from the aluminium industry (8).

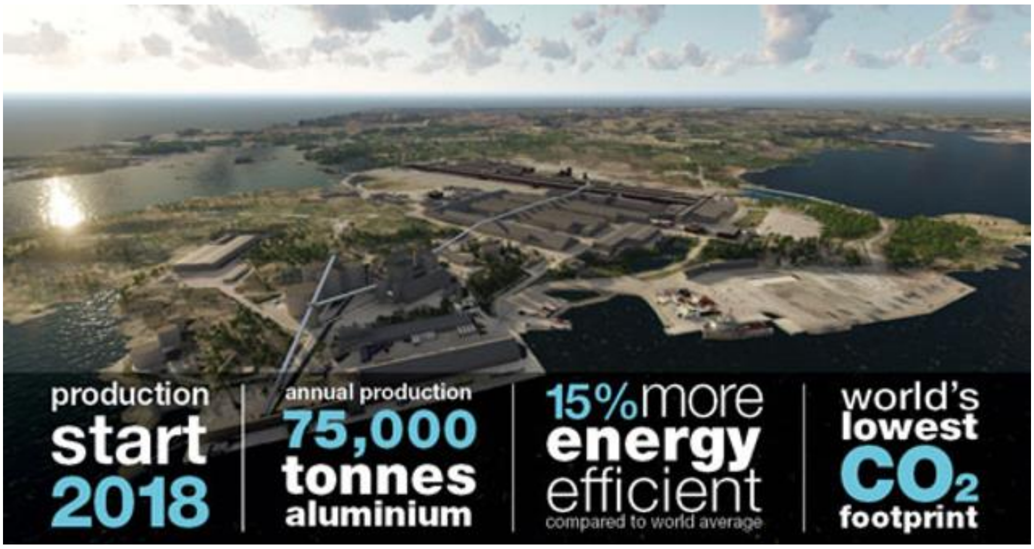


Figure 3: Characteristics of the new technology pilot at Karmøy

Source: (8)

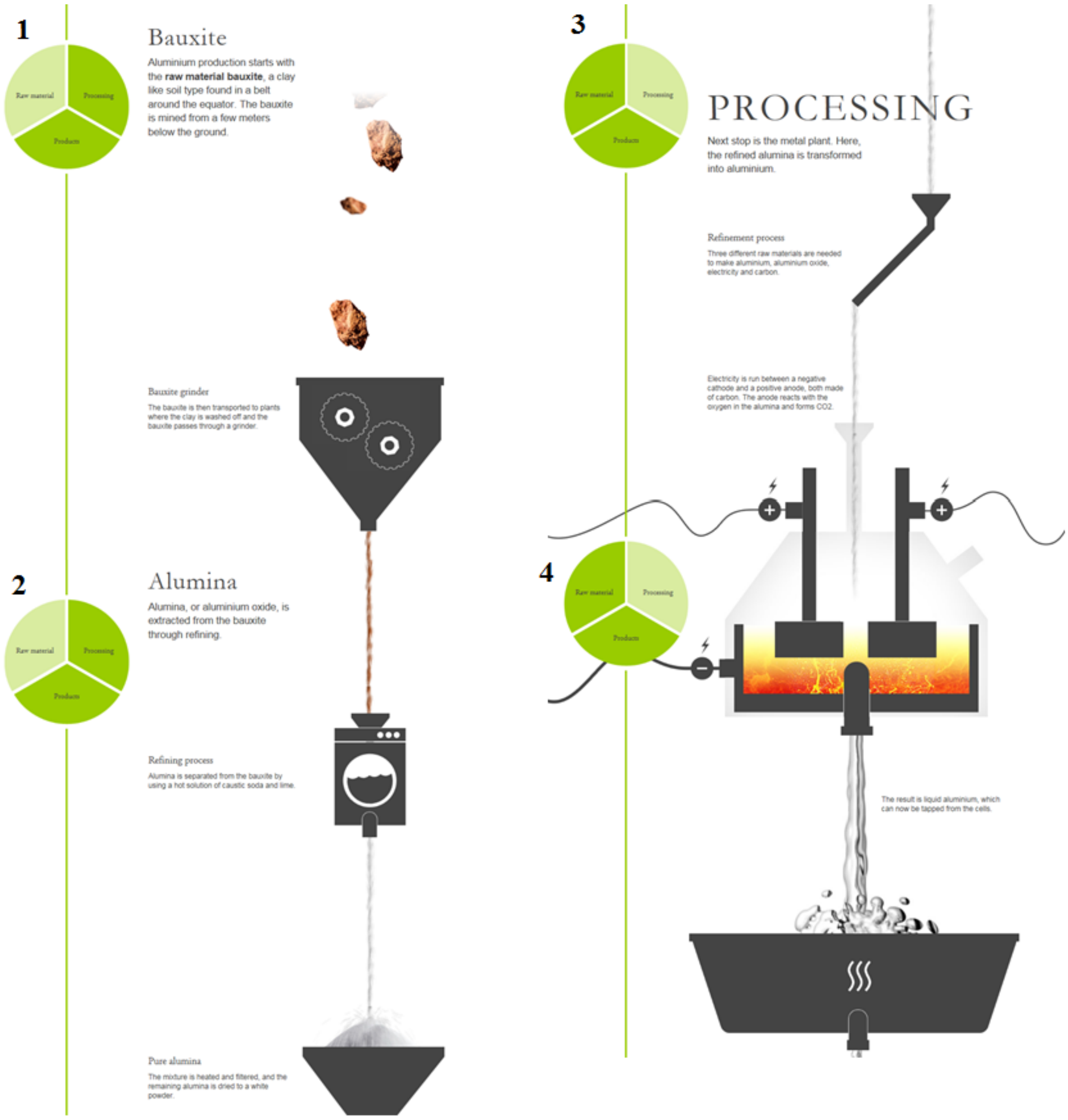
This figure shows an illustration of Hydro's aluminium plant at Karmøy, including the new technology pilot and the pilot's essential qualities.

2.2 Application - How aluminium is made

Production of aluminium is an extensive process. It starts with extraction of the raw material bauxite, found a few meters below ground close to equator in a clay like form. The clay is washed off, and the bauxite is sent through a grinder. Then alumina, also called aluminium oxide, is separated from the bauxite using a hot solution, the separated alumina is then heated, filtered and dried to a white powder - pure alumina (9). To produce 1 pound aluminium, 2 pounds of alumina is needed, to produce 2 pounds of alumina 4 pounds of bauxite is needed (10).

The next step in aluminium's journey is processing at the metal plants, example Hydro Karmøy. Here the alumina/aluminium oxide is transformed in to aluminium with help from two other raw materials, electricity and carbon. Electricity is run between a negative cathode and a positive anode, both made of carbon, together forming a cell where the aluminium is produced in an electrolysis process. There will then be a reaction between the materials in the cell, and the result is liquid aluminium (9). This is how the production of primary aluminium works, while secondary production is recycling of existing aluminium.

The entire process from raw material to recycling is illustrated in the Figure 4 and Figure 5.



Bauxite

Aluminium production starts with the **raw material bauxite**, a clay like soil type found in a belt around the equator. The bauxite is mined from a few meters below the ground.

Bauxite grinder

The bauxite is then transported to plants where the clay is washed off and the bauxite passes through a grinder.

Alumina

Alumina, or aluminium oxide, is extracted from the bauxite through refining.

Refining process

Alumina is separated from the bauxite by using a hot solution of caustic soda and lime.

Pure alumina

The mixture is heated and filtered, and the remaining alumina is dried to a white powder.

PROCESSING

Next stop is the metal plant. Here, the refined alumina is transformed into aluminium.

Refinement process

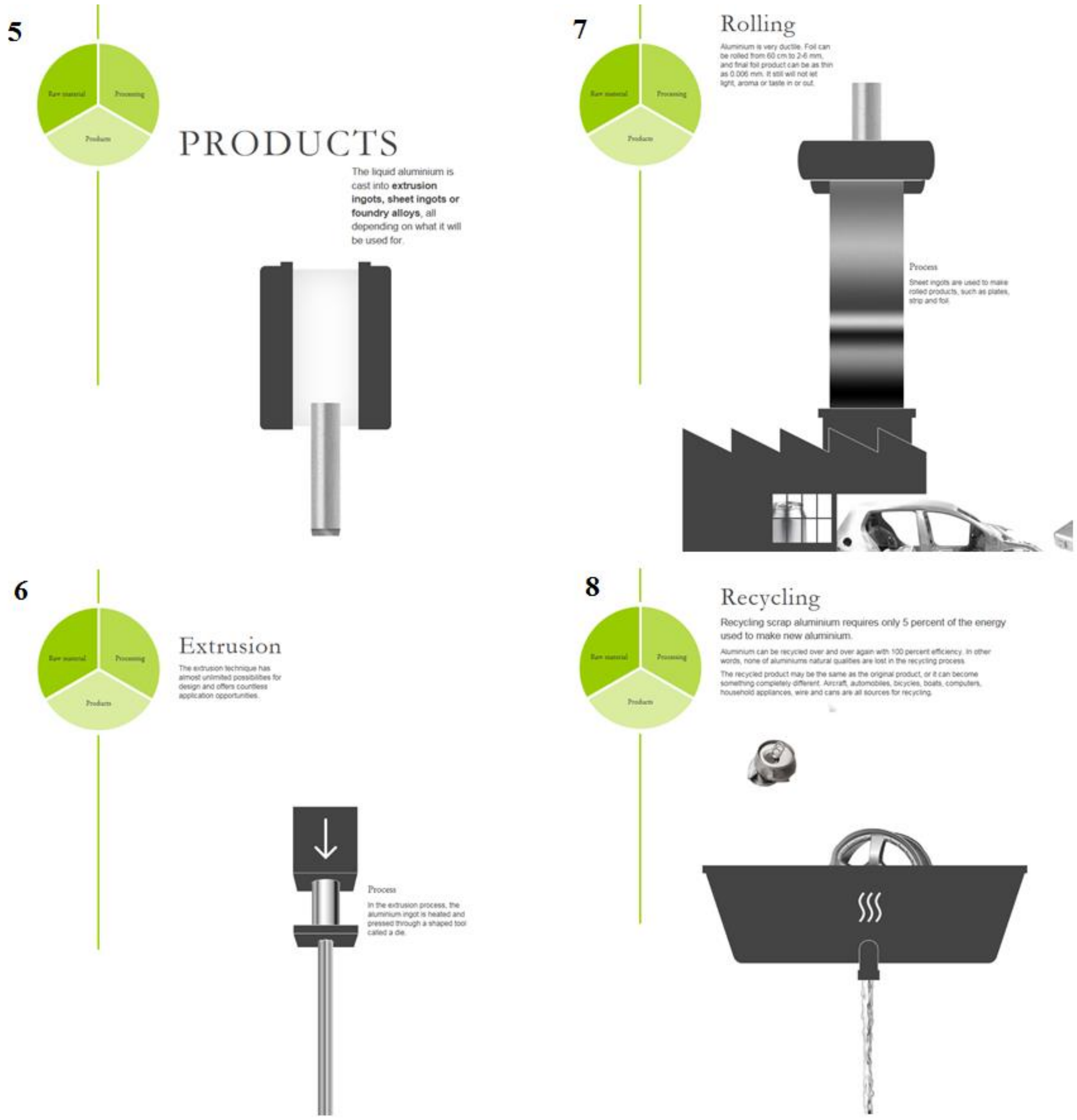
Three different raw materials are needed to make aluminium, aluminium oxide, electricity and carbon.

Electricity is run between a negative cathode and a positive anode, both made of carbon. The anode reacts with the oxygen in the alumina and forms CO2.

The result is liquid aluminium, which can now be tapped from the cells.

Figure 4: How aluminium is made, raw material and processing

Source: (9)



The liquid aluminium is cast into **extrusion ingots, sheet ingots or foundry alloys**, all depending on what it will be used for.

The extrusion technique has almost unlimited possibilities for design and offers countless application opportunities.

In the extrusion process, the aluminium ingot is heated and pressed through a shaped tool called a die.

Aluminium is very ductile. Foil can be rolled from 60 cm to 2-6 mm, and final foil product can be as thin as 0.006 mm. It still will not let light, aroma or taste in or out.

Sheet ingots are used to make rolled products, such as plates, strip and foil.

Recycling scrap aluminium requires only 5 percent of the energy used to make new aluminium.

Aluminium can be recycled over and over again with 100 percent efficiency. In other words, none of aluminiums natural qualities are lost in the recycling process.

The recycled product may be the same as the original product, or it can become something completely different. Aircraft, automobiles, bicycles, boats, computers, household appliances, wire and cans are all sources for recycling.

Figure 5: How aluminium is made, products and recycling

Source: (9)

When the liquid aluminium is ready it is tapped from the cells by tapping carriages, and transported to different units, for transformation into extrusion ingots, sheet ingots or foundry alloys - depending on what it will be used for and what the final product will be (11). Extrusion and rolling are two techniques where the ingots are transformed into products which later can be used to make bikes, chairs, ladders, car parts, drinking cans just to name a few (9).

Recycling of scrap aluminium is also an important part of the aluminium life cycle, and it only requires 5 percent of the energy used to produce primary (9). Since Aluminium is the most recyclable of all materials, discarded aluminium is more valuable than any other item in the recycling bin. In fact, nearly 75 percent of all aluminium produced, are still in use today (12), which is an important measure towards a greener aluminium industry. In addition to be a recyclable material, aluminium also has a lot of other excellent properties such as lightweight, corrosion resistant, high durability, flexible, strong and good conductivity. All these qualities make aluminium an essential element of daily life, and we are in fact surrounded by aluminium everywhere. Cars, planes, boats, buildings, cell phones, computers, household appliances and containers for food and beverages are only some of the products we are surrounded by in our everyday life, that are made of aluminium (9).

2.3 Maintenance

Industrial maintenance has the last half-century evolved very much, from a 'non-issue' to a strategic concern (13). At first maintenance was only an inevitable part of the production, while today a good maintenance strategy is considered as a key to success (14). Pintelon and Parodi-Herz writes (14) that most authors writing about maintenance management agree on the definition of maintenance being a "set of activities required to keep physical assets in the desired operating condition or to restore them to this condition". Choosing the right maintenance strategy is important, and the best solution will vary depending on the industry and equipment being maintained.

Table 1: Definitions

Expression	Meaning
Maintenance actions	Basic maintenance intervention, elementary task carried out by a technician
Maintenance Policy	Rule or set of rules describing the trigging mechanism for the different maintenance actions
Maintenance concept	Set of maintenance policies and actions of various types and the general decision structure in which these are planned and supported

Source: (14)

2.3.1 Corrective and Precautionary maintenance

Maintenance actions can be divided in to two categories, Corrective Maintenance (CM) and Precautionary Maintenance (PM). CM actions are done after a breakdown, failure or loss of function of equipment and/or systems. Basically, it works the way "don't touch it until it breaks, then fix it". While PM actions can be divided into preventive, predictive, proactive or passive. These actions aim to avoid failure or breakdown from happening, by planning and performing maintenance on the equipment/system before something goes wrong. Examples of precautionary actions are lubrication, bearing replacement, inspection rounds, condition monitoring etc (14).

2.3.2 Computerized Maintenance Management System

Computerized Maintenance Management System (CMMS) is a computer software to simplify maintenance management. These days it is easily taken for granted that all maintenance data is stored on a computer, but before the 1980s the maintenance actions often was recorded with pen and paper (15). When all information about maintenance is stored on a computer the data analysing, creation of maintenance plans and generating accurate maintenance reports becomes much easier, and it also becomes easier for the companies to have a preventive maintenance policy leading to extended lifetime of assets and reduction of cost and increased profits (15).

As Micromain writes «CMMS solutions give technicians the freedom to focus less on paperwork and more on hands-on maintenance» (15), which is true. CMMS allows engineers, technicians and mechanics to prioritize the maintenance and improving efficiency of the machines, give insight to which maintenance actions that is needed, what to prioritize and allows managers to make the best decisions.

There exist many different companies providing their own version of CMMS software, they specialise in different industries or have different focus, but they all basically do the same thing; Simplify the management of maintenance by systemizing all the data about maintenance and using it do make analyses, reports, plans and prioritizing as well as information management and work control (15).

2.3.3 Level of Repair Analysis

Level of Repair Analysis (LORA) is defined by Department of Defence – United States of America (16) as "An analytical methodology used to assist in developing maintenance concepts, influencing design, and establishing the maintenance level at which components will be replaced, repaired, or discarded based on constraints obtained through economic, noneconomic, and sensitivity evaluations, as well as operational readiness requirements."

LORA is used to determine if it is economically feasible to repair components or parts of system, or if the better option is to discard them and replace with new, according to professor in the course Operation and Maintenance Management spring 2017 at University of Stavanger, Idriss El-Thalji.

2.4 Method theory

2.4.1 System Dynamics with Vensim

This master thesis uses system dynamics to study and analyse maintenance data. System dynamics has been developed to integrate engineering techniques for understanding data and feedback from different systems (17).

Vensim is a simulation software that uses system dynamics to make computer simulations for different purposes in the industry, including improving performance of real systems. Vensim enables companies to connect data with advanced algorithms and make simulations and models that will help them to better understand their systems and improve its performances (17). Vensim Personal Learning Edition (PLE) is a slightly reduced version of the original Vensim, that has been designed to lower the barriers to the beginning system dynamics modeler. Vensim PLE is just as fully functional as Vensim, it is free of use and it is ideal for classroom use and personal learning of system dynamics. Vensim is developed by Ventana Systems Inc. (17).

2.4.2 SAP

SAP stands for Systems, Applications and Products, and the company is the world's largest provider of enterprise application software. SAP has a big focus on real time analytics, developing technologies that will make an impact on the world. They have 91 000 employees in 130 countries and almost 190 000 customers in more than 180 countries. They are passionate about sustainability and social responsibility and they invest a lot in many different areas, including lifesaving research (18). SAP is committed to make the world a better place with technology, where economy, society and environment prosper together. They want to be a leading company that can help their customers to run a simple, digital enterprise based on information and data in real-time (19).

SAP's portfolio is very comprehensive and covers all sorts of industries all over the world. This also means that they deliver a huge amount of different solutions for all business process across all industries (18).

2.4.3 Diagramming

Draw.io is a free-to-license web application for everyone, where one can use the software to create high quality diagrams, and store the diagrams with a cloud sharing service or on a device (20). Draw.io is used to make models and illustrations of system structure in this thesis.

3 Research methodology and model development

In this chapter the research method and the 'recipe' for how to make the dynamic model is developed, by creating steps that needs to be followed to be able to answer the key questions in this master thesis. The key questions are; can the maintenance policy be improved, is a global maintenance policy preferable to a local and whether one should repair vs replace.

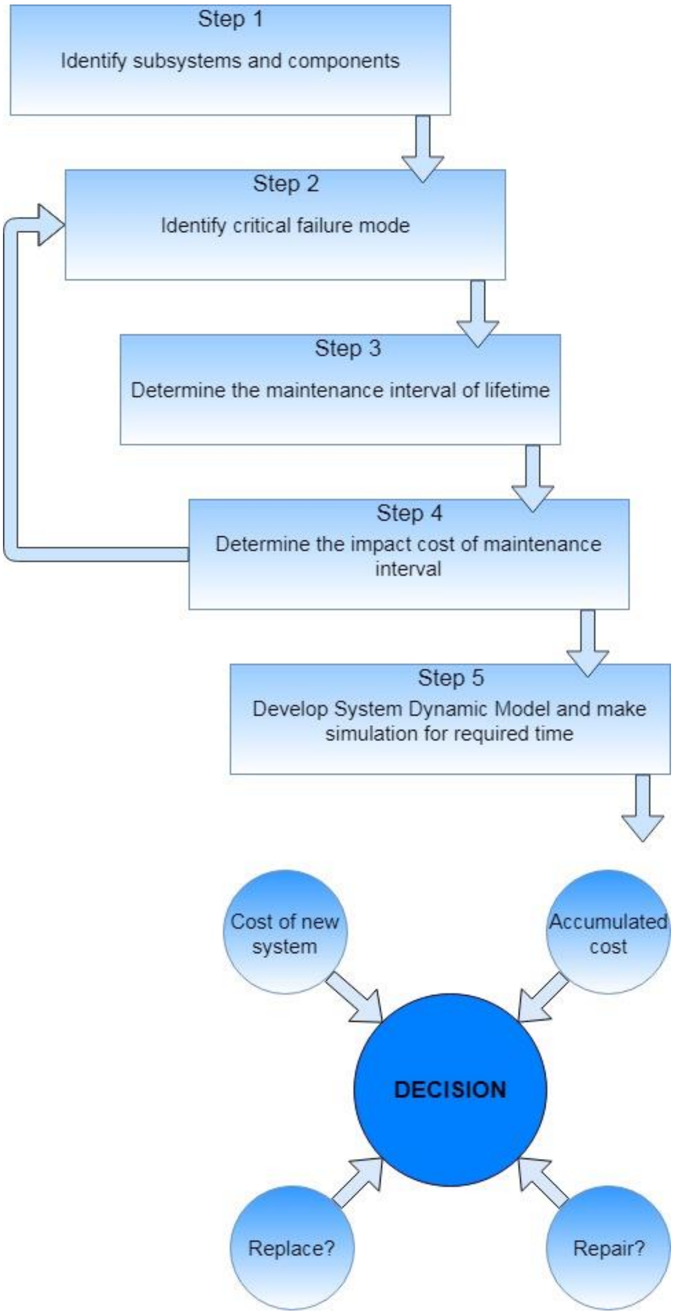


Figure 6: Model development step by step

Figure 6 shows how the progress in this master thesis have been. The model is made as a loop so that HAK can go back and continue adding components into the analyzation, to get a complete understanding of how the maintenance cost would develop and what decision to they should make.

To identify the subsystem and the components that ought to be used as an example is this case study, a lot of data had to be analysed. The subsystem and components being studied in this case should be critical for the system, but at the same time provide enough analysable data so that a conclusion could be made.

This model, Figure 6**,** shows the main steps towards an answer for the research question provided in *chapter 1.3 Research question and project objective*: "How can a global perspective of specific critical assets be analysed and visualized to support equipment replacement decisions i.e. repair vs preplace?"

The first step towards answering the research question was to identify a critical subsystem in the selected system, and then select two to three critical components to analyse further. After the subsystem and the components where selected based on the failure data provided, the most critical failure mode should be determined, this being step 2. However, if failure mode could not be determined due to lack of registration of this in the collected data, the author would try to distinguish between the failures in another way.

In step 3 and 4 the maintenance interval and the associated costs of the selected components should be established, including determining the impact of the maintenance interval based on the failure data that was provided. This maintenance interval would then be assumed to be repeated for the next 20 years, or how long the simulation would be made for.

The maintenance cost interval should then be used in step 5 to develop a system dynamic model. The model will be used to simulate the maintenance lifetime cost with both a local and a global focus, and comparing it with the cost of buying a new system. Based on this simulation the maintenance department at HAK may be able to make better decisions about repair vs replace.

3.1 Step 1: Identify subsystem and components

The case that are studied in this master thesis is a vehicle that is central in aluminium production, a tapping carriage. The tapping carriage is a big vehicle with a comprehensive system. Due to time and work constraints, only one subsystem in the tapping carriage will be evaluated. Then 2-3 components inside this subsystem will be chosen to be reviewed and it will be done an evaluation of the chosen components failure data. Based on this analyzation a simulation and a model will be made.

To choose which subsystem that will be evaluated, the tapping carriage needed to be divided in to system of systems. The tapping carriage can be divided into 10 subsystems, which can be seen in Figure 7.

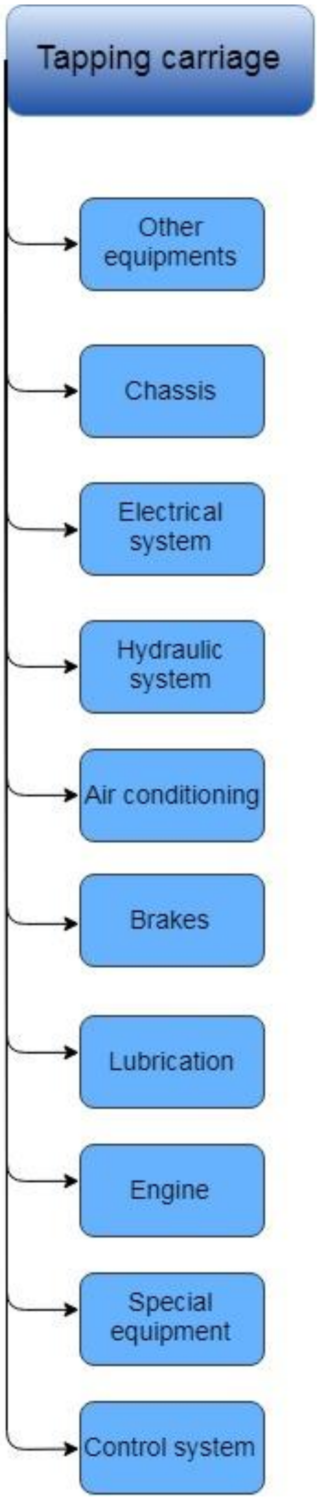


Figure 7: Breakdown structure of the tapping carriage

Larsen, head of maintenance at HAK provided failure data from SAP, allowing the author to evaluate the vehicle's most critical subsystem based on numbers of failures. After the subsystem was chosen, the next step was to choose three critical components that would be used to make the dynamic model and simulation in step 5. The failure data for the chosen subsystem needed to be thoroughly reviewed and analysed, sorted into number of failures for each component and then choose to work further with the components with the most failures.

3.2 Step 2: Identify critical failure mode

In the next step the failure data from the chosen components should be used to identify the critical failure modes of each component. This should be done to identify the criticality of each failure happening to the components, and choosing which failure mode to focus on based on the frequency of the different failure modes.

However, if failure mode is not registered in the failure data, another solution should be chosen to distinguish between the different failures.

3.3 Step 3: Determine the maintenance interval of lifetime

When subsystem, components and the criticality of the failure mode was determined, the next step was to determine the maintenance interval of the components. How often did the failure modes repeat, how long between each failure, and would this interval be representative to repeat in to the future? This are questions that needed to be evaluated.

3.4 Step 4: Determine the impact cost of maintenance interval

Larsen also provided cost data from SAP related to the chosen components. This data was used to make an overview of how big the expenses for each maintenance operation were, both material cost for spare parts and equipment used, cost for personnel and a setup cost was included. Setup cost is the cost to transport the vehicle from the production unit and into the workshop.

This cost-data could then be used to make a diagram of the costs connected to each component, and further be used when developing the system dynamic model for a maintenance cost interval

3.5 Step 5: Develop System Dynamic Model and simulate for required time

In the last step the analysed data from step 1 to 4 was used to make a simulation and a model that would help answer the key questions in this thesis. The maintenance interval with the associated costs would be plotted into a program that would make a simulation of how the maintenance costs would develop during a given timeframe.

The simulation program that would be used in this master thesis is Vensim.

4 Data collection chapter

This chapter is about the data collected from the case company.

4.1 About Hydro

Hydro is a fully integrated aluminium company with about 35 000 employees in 40 countries worldwide. Their value chain reaches from extractions of bauxite, refining of alumina, generating energy and production of aluminium (21). With the Sapa acquisition happening in 2017, Hydro is now the only global company in the aluminium industry that is fully integrated across the value chain and markets (22).

Hydro produces aluminium in five different locations in Norway. Karmøy in Rogaland is one of these plants. The production of aluminium started here in 1967 and are still going strong. As mentioned in *chapter 2.1 - Why aluminium?*, earlier this year the Karmøy technology pilot stated producing aluminium with the world's most climate and energy-efficient technology. The pilot will add 75 000 tonnes of aluminium production per year to the already existing capacity of approximately 200 000 tonnes per year (8).

Primary aluminium is only one step in the aluminium value chain. The figure below shows the whole value chain, from raw material to the never-ending life cycle of aluminium products.

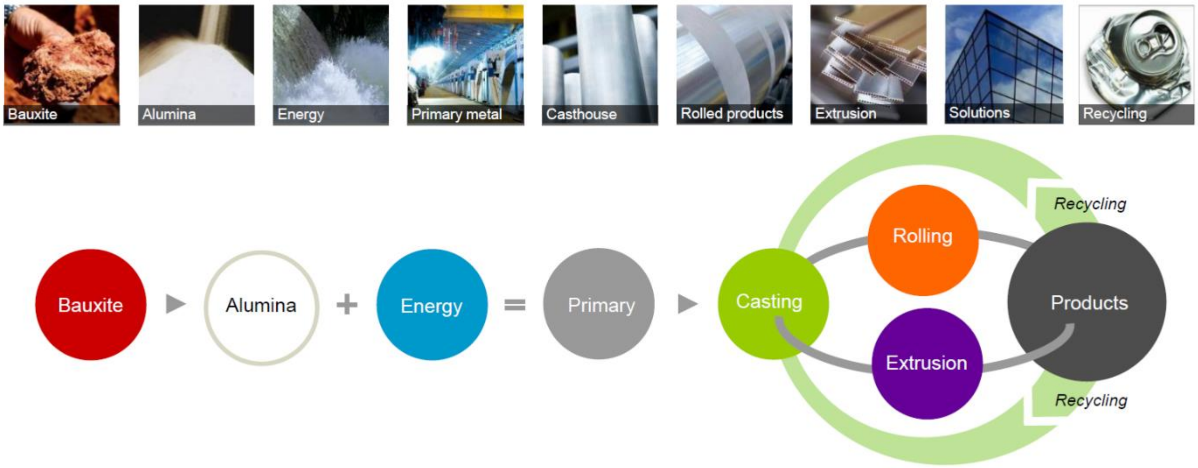


Figure 8: The Aluminium Value Chain

Illustration from Norsk Hydro ASA, intranet page.

4.2 Hydro Aluminium Karmøy

[1]

In addition to production of primary aluminium at Karmøy, the aluminium is distributed to different units - casting houses for production of wire rod, ingots and alloys, and to Karmøy Rolling Mill for production of coils and sheets (23).

Besides the electrolysis halls and the casting houses there are also other units at HAK. These other units' main function is to support the production of primary aluminium and the following products. Maintenance department, rodding, technical support, logistics, Environment Health and Safety department, Human Resources, Research and development, laboratory and IS/IT are some of the supporting units, they all contribute to the process in their own way and they are all crucial for the aluminium process to function as it should.

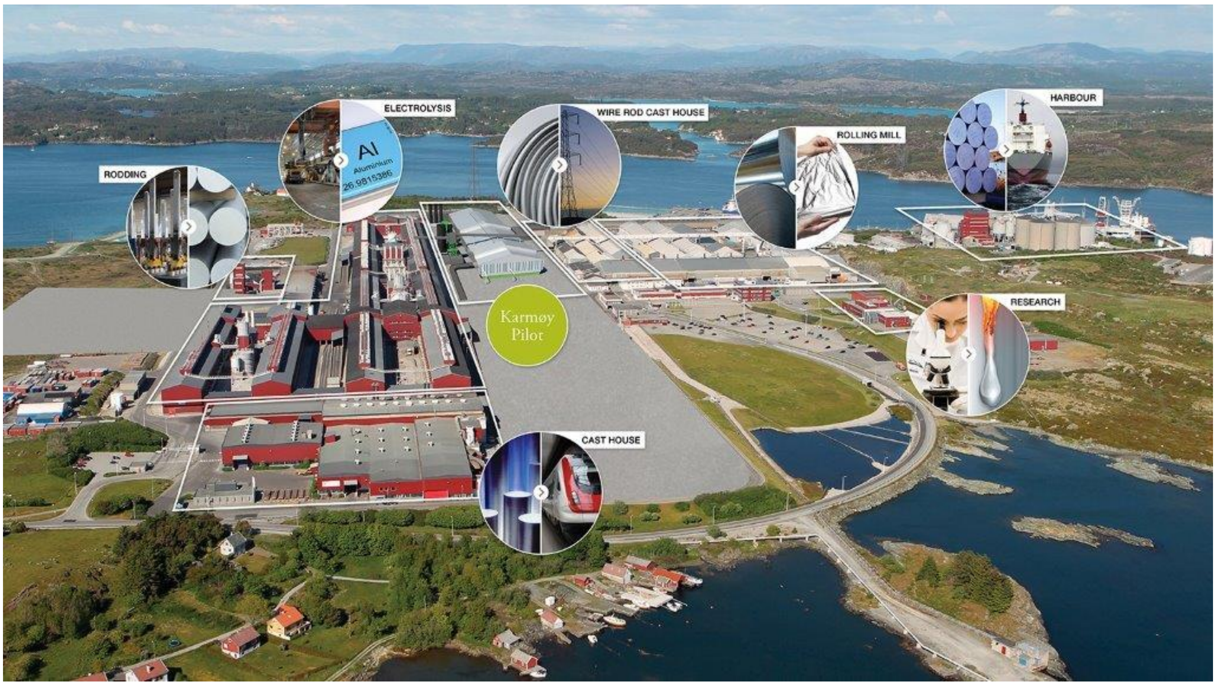


Figure 9: The aluminium plant at Karmøy and the different units located in the factory

Picture from Norsk Hydro ASA, intranet page.

Figure 9 shows the location to some of the units at HAK's plant. In additions to the units that are tagged in the picture, there are as mentioned many other units as well. This master thesis is written in collaboration with the Maintenance department and uses tapping carriages as a case study to solve the problem formulated in chapter 1.

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[1] Some of the information in this chapter is the authors own knowledge from working in the case company as a holiday substitute, and it is therefore not referenced.

4.2.1 Maintenance

The production of aluminium is a comprehensive process, so operative and functioning equipment is very important to have an effective aluminium production. For equipment to function as it should, maintenance is necessary, and the right maintenance policy can be a crucial element for an effective and efficient production. How to decide between the different maintenance policies are not always easy, and there are many aspects that needs to be taken in to consideration when the maintenance strategy is made and what decision-making tools that should be used.

HAK are divided into different units, where everyone has an influence on each other and on the aluminium production process. It is the same with maintenance of the equipment being used. The "owners" and daily users of the equipment, the maintenance department (both employed by HAK) and the mechanics (employed by Bilfinger) work closely together. Electrolysis department owns the tapping carriages, and are the ones using them on a daily basis. But the maintenance department, together with Bilfinger, are responsible for maintaining the equipment and perform both corrective and preventive maintenance as well as all scheduled controls and services.

(24) Bilfinger Industrial Services Norway is a multidisciplinary supplier of a wide range of industrial services. Bilfinger is located within the gates of HAK, and they perform tasks for Hydro within maintenance, modifications and operations, engineering and manufacturing among other things. At HAK the employees at Bilfinger's workshops, is responsible for following the preventive maintenance plans, in addition to take care of corrective maintenance when these situations occur.

4.2.1.1 Corrective Maintenance

If something happens with the equipment while it's being used, the operators report it. Then the maintenance department in cooperation with Bilfinger will figure out what is wrong, what needs to be maintained or replaced. A work order is then made and sent to Bilfinger for them to perform the needed actions, based on the criticality of the failure.

Hydro's maintenance strategy is mainly corrective, with some exceptions. There is a strong tendency to letting the equipment run to failure, before making an evaluation about what needs to be done. However, there are both 6 and 12 months services in addition to check-ups after X-hours of operation on a lot of the equipment, machines and vehicles.

(4)

4.2.1.2 Preventive Maintenance

As mentioned Hydro's maintenance strategy is mainly corrective, but some preventive maintenance is done as well. Not all equipment has preventive maintenance plans, but the tapping carriages have at some areas.

Some years ago, it was put a lot of work into making a preventive maintenance plan for some of the most vulnerable parts in the tapping carriages. The reason why this vehicle was prioritized is that there had been a lot of problems with the propulsion hoses, causing a huge mess if they ruptured while the vehicle was in operation. The time and costs of the repair including cleaning up the mess after the rupture, was something that wished to be avoided. That is why there were initiated a replacement plan for the propulsion hoses at the SF controls (4).

A lot or work have been put into the assignment of creating preventive maintenance plans, but there is still a lot work to be done. Rydland says the plan is to implement preventive maintenance planes on more equipment than there is today (4). Rydland works in the maintenance department at HAK and is responsible for all the vehicles at the plant. He makes sure maintenance is performed after the scheduled planes and controls, both corrective and preventive.

(4)

4.2.2 Description of the selected system

There are a lot of critical equipment being used in the aluminium production, one of them being the vehicle used to tap metal from the electrolysis cells. This vehicle is responsible for draining aluminium from the cells where the aluminium is ready, and then transport the liquid aluminium to the next step in the process. Optimal function of these vehicles is very important, because if the tapping carriages don’t function and the aluminium can’t be tapped it will be critical for both the production of primary aluminium but also the products made in the casting houses. Since the aluminium production is an ongoing process and there are 288 cells (+60 from the pilot) that needs to be tapped about every second day, the tapping carriages needs to be operative 24/7 (11).

Since the tapping carriages is so central in the aluminium production process, the maintenance of them is equally important. There are good maintenance plans in place, and a high focus on performing the maintenance according to these plans. Keeping the vehicles up and running and allowing them to perform their duties so that the aluminium production can continue as it should, is very important.

Figure 10 shows how the tapping carriage is divided into subsystems and an example of how the subsystems are divided into components and parts.

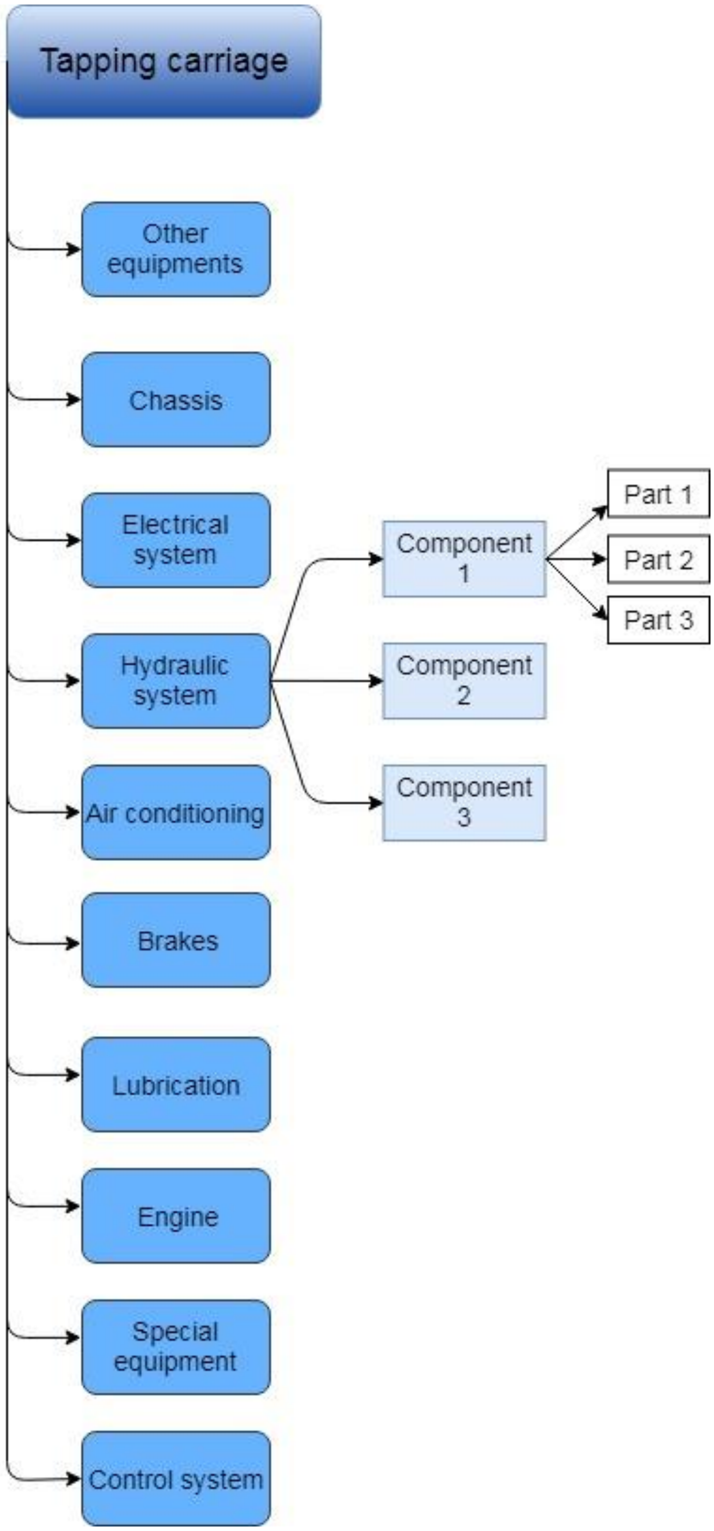
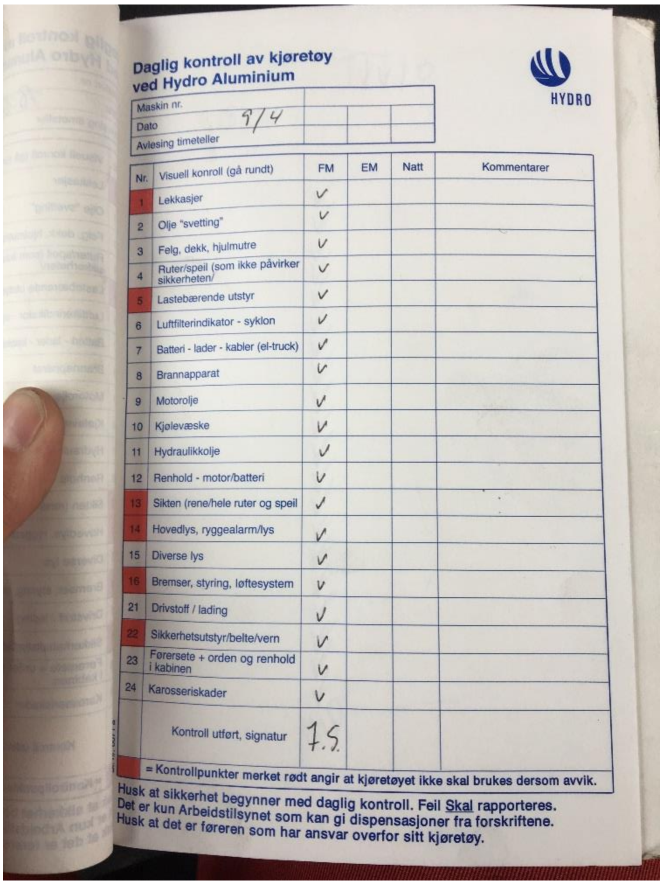


Figure 10: Breakdown structure of the tapping carriage

The tapping carriages is divided into 10 subsystems, showed in Figure 10. Then each subsystem is divided into several components, and the components are again divided into parts. Pump, cylinder and valves are three examples of components in the hydraulic system, each of these components consists of many smaller parts like for example gaskets, hoses, filters and pipes.

Tapping of aluminium from the electrolysis cells is a continuous task that are ongoing 24/7. The operators that tap aluminium work shift, and there are 4 workers driving the tapping carriages at all time. Their shifts start with an update from the previous shift, followed by a review of a check list before the vehicle can be used (11).



Daglig kontroll av kjøretøy ved Hydro Aluminium

Maskin nr.			
Dato 9/4			
Avlesing timeteller			

Nr.	Visuell konroll (gå rundt)	FM	EM	Natt	Kommentarer
1	Lekkasjer	✓			
2	Olje "svetting"	✓			
3	Felg, dekk, hjulmutre	✓			
4	Ruter/speil (som ikke påvirker sikkerheten/	✓			
5	Lastebærende utstyr	✓			
6	Luftfilterindikator - syklon	✓			
7	Batteri - lader - kabler (el-truck)	✓			
8	Brannapparat	✓			
9	Motorolje	✓			
10	Kjølevæske	✓			
11	Hydraulikkolje	✓			
12	Renhold - motor/batteri	✓			
13	Sikten (rene/hele ruter og speil	✓			
14	Hovedlys, ryggealarm/lys	✓			
15	Diverse lys	✓			
16	Bremser, styring, løftesystem	✓			
21	Drivstoff / lading	✓			
22	Sikkerhetsutstyr/belte/vern	✓			
23	Førersete + orden og renhold i kabinen	✓			
24	Karosseriskader	✓			
	Kontroll utført, signatur	T.S.			

🟥 = Kontrollpunkter merket rødt angir at kjøretøyet ikke skal brukes dersom avvik.

Husk at sikkerhet begynner med daglig kontroll. Feil Skal rapporteres.
Det er kun Arbeidstilsynet som kan gi dispensasjoner fra forskriftene.
Husk at det er føreren som har ansvar overfor sitt kjøretøy.

Figure 11: Daily control checklist of vehicles at Hydro Aluminium

Picture taken by the author.

Figure 11 shows a picture of the checklist that the operator must run through before operating the vehicle. As seen in the picture there are 24 points to check, out of these there are 6 critical points which are marked red. If one of the red points is not in perfect conditions, the vehicle must be parked and cannot be used until mechanics have looked at the problem. If some of the other points are not in perfect shape the vehicle can be used, but the operator must report the error, so it can be scheduled a repair.

After a run through of the check list, tapping can begin. Inside the vehicle a screen shows which cells that are next in line to be tapped, how many tonnes aluminium to tap from each cell and in which casting house the aluminium will end up. After the correct amount of aluminium is tapped, the drivers delivers the aluminium to the Ram station, where the aluminium is added aluminium fluoride before it is delivered to the casting houses for further processing (11).

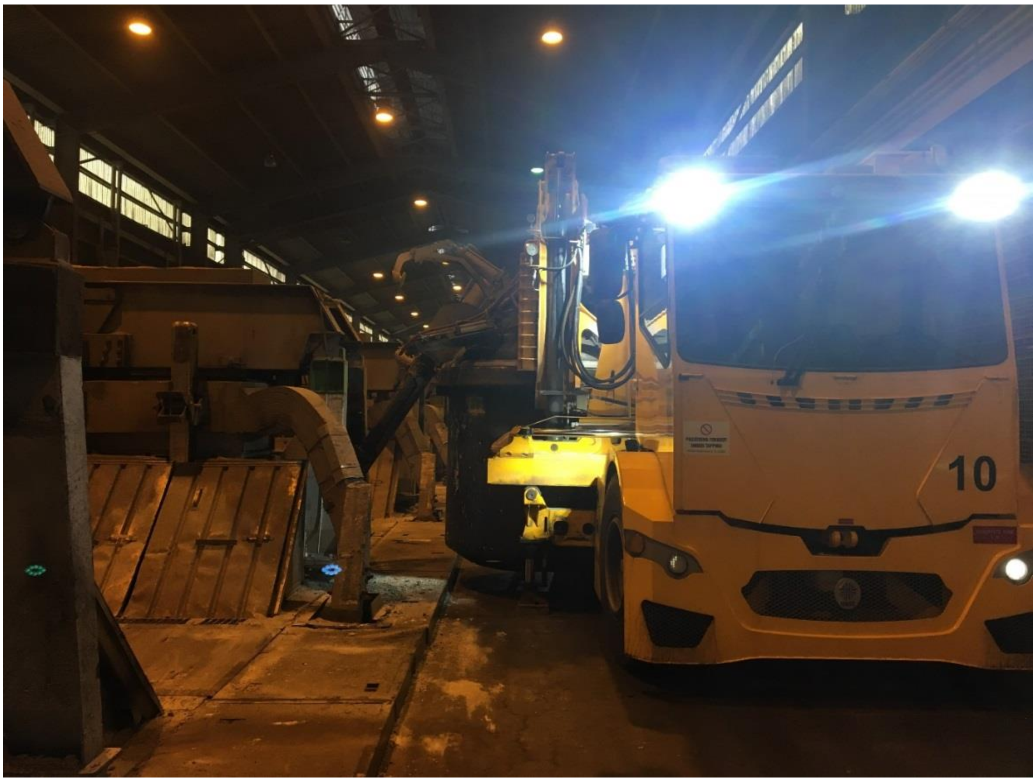


Figure 12: Tapping carriage while tapping aluminium from a cell in Prebake

Picture taken by the author.

Figure 12 is a picture of the tapping carriage in operation. In the middle of the picture one can see the draining ‘trunk’ going down in the cell to drain the liquid aluminium and transfer it in to the pot on the truck.

4.3 Data about the tapping carriage

To better understand the process of tapping aluminium and how the tapping carriages work, the author had a conversation with Thor Arne Dommersnes as well as a ride-a-long in one of the vehicles in operation. Dommersnes works as a technical supervisor at HAK.

During the conversation with Dommersnes and the operator of the tapping carriage several things was talked about, such as:

- The main function of the vehicle
- How the draining system works
- The checklist before operating the vehicle
- The system saying which cells to tap
- How the operators work and their daily routines
- The difference between the new and the old vehicles
- Comfort while driving
- How often the cells are tapped.

When the author had enough knowledge about the system, more specific data about the tapping carriage could be gathered. The rest of the data that was collected was provided from Leif Tore Larsen and Tor Magne Rydland in the maintenance department.

In addition to the checklist that the operators run through before operating the vehicle, the maintenance department also had a checklist for maintenance of the tapping carriage ‘FV MTV mor sjekkliste’, found in Feil! Fant ikke referansekilden.. This checklist consists of many maintenance actions including an overview saying when each action should be completed and exactly which actions to take.

(11)

4.3.1 Data about failures

In addition to data about the function of the tapping carriages and how the maintenance is scheduled and performed, real maintenance data about failures, orders and costs are also needed to answer the key questions in this master thesis.

To do the planned analysis, simulation and model creation the author was provided with all the failure data connected to tapping carriage number 1 at HAK.

‘Feildata TV1’, ‘Kostander Materiell’ and ‘Kostander ordre’ was three excel sheets that were downloaded and transported from failuredata stored in SAP. Since the author did not have any experience with SAP and learning how to use it would be too comprehensive, supervisor and head of maintenance at HAK Leir Tore Larsen, did this job.

The failure data provided the information needed to do the research and analyzation part in this master thesis. The data contained information about all the maintenance that were done on tapping carriage number 1 from 2010 to 2017. In addition to information about what maintenance operations that were performed, when it was done and so on, information about the associated costs were also provided. This way information about the subsystem and components could be connected and used for further simulation.

Due to the complexity of the excel sheets containing all the information about the failure and cost data, it will not be possible to add these as attachments in this master thesis. However, several snapshots from the spreadsheets are provided in chapter *5 Data analysis*, as well as a snapshots from a collection spreadsheet, containing all the data that was related to the chosen subsystem and components, in Appendix**.**

5 Data analysis

This chapter explains how the data analysation was done step by step, from reviewing failure data to making a system dynamic model by using the simulation program.

As explained in *chapter 4 - Data collection chapter*, there was a lot of data to look through to be able to complete steps 1-5 and make a conclusion based on this. Larsen and Rydland from HAK provided failure data from the studied case, tapping carriage number 1, including spreadsheets of material cost, cost per order, preventive maintenance plans, worksheets showing maintenance done each year and so on. All this data were thoroughly reviewed and were the basis for the analysis done in this paper.

5.1 Failure data

The author started with reviewing the failure data that was collected from SAP, 'Feildata TV1'**,** and based on this information rank the criticality of the system, see how often failure strikes in the different sub systems and which components that where most exposed for failure. This procedure was quite extensive because the tapping carriage is a complex system with many subsystems and associated components.

5.1.1 Identify critical subsystem

Figure 13 below shows a clipboard from 'Feildata TV1', and in the column to the right the number of failures on each subsystem are shown. As seen from Figure 13 as well as Figure 7 in *chapter 3.1 - Step 1: Identify subsystem and components*, 'Tappevogn NR01' are divided into 10 different subsystems. In SAP there are also one 'collection' unit called "TAPPEVOGN NR01 HYDEQ" where undefined failures are placed.

Count of Rapport			
Betegnelse	Kodetekst	Beskrivelse	Totalt
⊞ ANNEN UTRUSTNING TAPPEVOGN NR01 HYDEQ			127
⊞ CHASSIS/FØRERHUS TAPPEVOGN NR01 HYDEQ			118
⊞ EL ANLEGG TAPPEVOGN NR01 HYDEQ			149
⊞ HYDRAULIKKANLEGG TAPPEVOGN NR01 HYDEQ			231
⊞ KLIMAANLEGG TAPPEVOGN NR01 HYDEQ			25
⊞ KRAFTOVERFØRING/BREMS TAPPEVOGN NR01			41
⊞ MOTOR/AVGASSYSTEM TAPPEVOGN NR01 HYDEQ			252
⊞ SMØREAPPARAT TAPPEVOGN NR01 HYDEQ			7
⊞ SPESIALUTRUSTNING TAPPEVOGN NR01 HYDEQ			117
⊞ STYRESYSTEM TAPPEVOGN NR01 HYDEQ			40
⊞ TAPPEVOGN NR01 HYDEQ			1626
Totalsum			2733

Figure 13: Failure data collected from SAP, showing the different subsystems

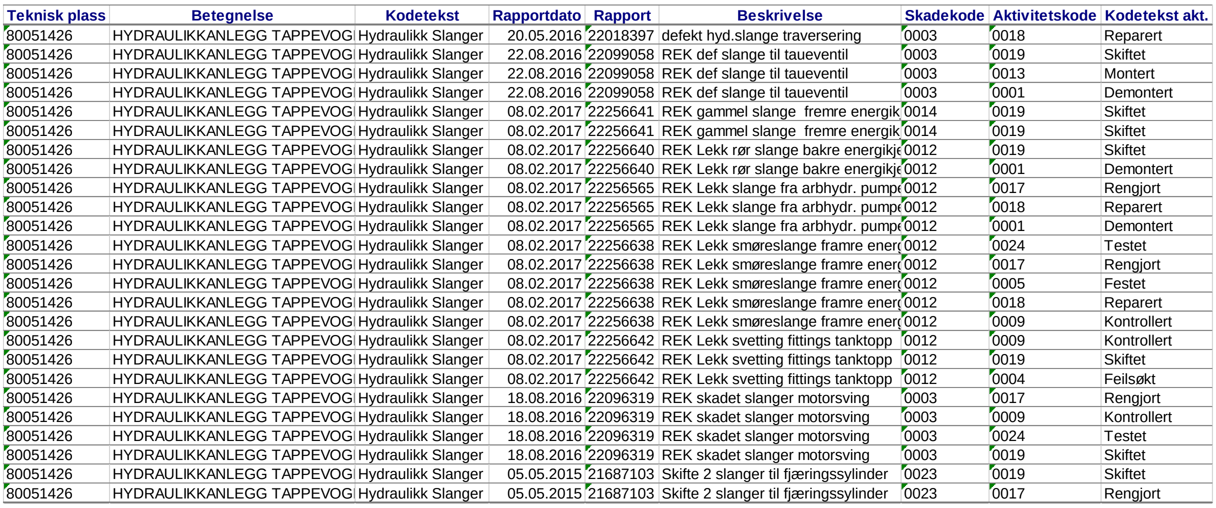
The challenge with this dataset was that the number showing how many failures that are registered on each subsystem don't actually show the total number of failures on the different components inside each subsystem, but rather the total number of activities done to repair the failures. This meant that each subsystem needed to be reviewed in detail to be able to sort out which system(s) that had the highest amount of failures and this way could be classified as the most critical subsystem.

Figure 14 is an example of how the subsystems are divided into components. Here one can see the subsystem ’MOTOR/AVGASSYSTEM’, meaning engine/exhaust system, has a total of 252 registered failures divided into 24 different components.

⊟ MOTOR/AVGASSYSTEM TAPPEVOGN NR01 HYDEQ	⊞ Elektrisk Batteri	5
	⊞ Elektrisk Startmotor	6
	⊞ Elektrisk STM- Motor	8
	⊞ Hydraulikk Fordelergear	30
	⊞ Hydraulikk Fremdriftspumpe	9
	⊞ Hydraulikk Pumpe	1
	⊞ Hydraulikk Tillegg	2
	⊞ Hydraulikk Vacuum	4
	⊞ Motor Dieselmotor	11
	⊞ Motor Dieselpumpe	15
	⊞ Motor Kjølerør / slange kompressor	8
	⊞ Motor Kjølevifte	1
	⊞ Motor Kjølevæske	16
	⊞ Motor Kompressor	4
	⊞ Motor Kuleledd	5
	⊞ Motor oljefilter	1
	⊞ Motor Oljekjøler	6
	⊞ Motor Pakninger	5
	⊞ Motor Radiator	8
	⊞ Motor Simmerringer	4
	⊞ Motor Smøreoljefilter	5
	⊞ Motor Tillegg	63
	⊞ Motor Vannpumpe	34
	⊞ Spesialutrusting Cooper king blåser	1
MOTOR/AVGASSYSTEM TAPPEVOGN NR01 HYDEQ Totalt		252

Figure 14: Failure data collected from SAP, showing components in a subsystem

Each of these components where once again reviewed closer, to determine the correct number of failures versus activities done to repair the failures.



Teknisk plass	Betegnelse	Kodetekst	Rapportdato	Rapport	Beskrivelse	Skadekode	Aktivitetskode	Kodetekst akt.
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	20.05.2016	22018397	defekt hyd.slange traversering	0003	0018	Reparert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	22.08.2016	22099058	REK def slange til taueventil	0003	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	22.08.2016	22099058	REK def slange til taueventil	0003	0013	Montert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	22.08.2016	22099058	REK def slange til taueventil	0003	0001	Demontert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256641	REK gammel slange fremre energik	0014	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256641	REK gammel slange fremre energik	0014	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256640	REK Lekk rør slange bakre energikj	0012	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256640	REK Lekk rør slange bakre energikj	0012	0001	Demontert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256565	REK Lekk slange fra arbhydr. pump	0012	0017	Rengjort
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256565	REK Lekk slange fra arbhydr. pump	0012	0018	Reparert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256565	REK Lekk slange fra arbhydr. pump	0012	0001	Demontert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256638	REK Lekk smøreslange framre ener	0012	0024	Testet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256638	REK Lekk smøreslange framre ener	0012	0017	Rengjort
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256638	REK Lekk smøreslange framre ener	0012	0005	Festet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256638	REK Lekk smøreslange framre ener	0012	0018	Reparert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256638	REK Lekk smøreslange framre ener	0012	0009	Kontrollert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256642	REK Lekk svetting fittings tanktopp	0012	0009	Kontrollert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256642	REK Lekk svetting fittings tanktopp	0012	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	08.02.2017	22256642	REK Lekk svetting fittings tanktopp	0012	0004	Feilsøkt
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	18.08.2016	22096319	REK skadet slanger motorsving	0003	0017	Rengjort
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	18.08.2016	22096319	REK skadet slanger motorsving	0003	0009	Kontrollert
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	18.08.2016	22096319	REK skadet slanger motorsving	0003	0024	Testet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	18.08.2016	22096319	REK skadet slanger motorsving	0003	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	05.05.2015	21687103	Skifte 2 slanger til fjæringssylinder	0023	0019	Skiftet
80051426	HYDRAULIKKANLEGG TAPPEVOG	Hydraulikk Slanger	05.05.2015	21687103	Skifte 2 slanger til fjæringssylinder	0023	0017	Rengjort

Figure 15: Failure data collected from SAP, showing registered failures

Figure 15 shows the failures that are registered on one of the components in the hydraulic system in the tapping carriage. In the column to the right there are listed an explanation for what actions that are done by the mechanics at the workshop. It is explained whether the component is repaired, changed, dismantled, cleaned, tested and so on. The column ‘Rapportdato’ in the middle shows when the work is performed, and as one can see there are many activities registered at the same date. These activities where then counted and registered as one failure in the analysation.

After the analysation on the collected data where gathered, it became clear that HAK do not distinguish between failure mode when logging the maintenance operation in SAP. The failures were hence ranked/sorted in groups based on if the component was changed or fixed/repaired instead.

This procedure was repeated on all the component in the all the subsystems in the tapping carriage, including the ‘collection’ unit, and the result are presented in Figure 16.

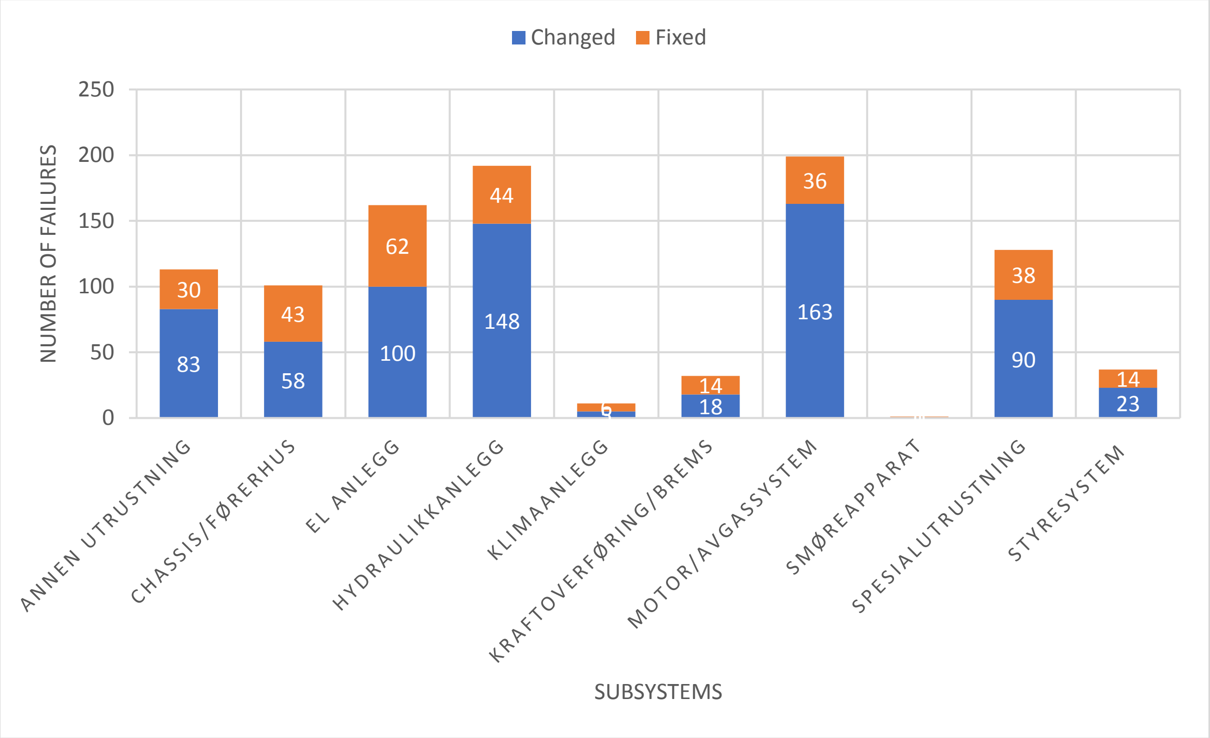


Figure 16: Number of failure registered on different subsystems in tapping carriage

As seen from Figure 16 the hydraulic system and engine are the two subsystems with the most failures, so the author decided to look further into one of these subsystems. After conversations and recommendations from Leif Tore Larsen, the hydraulic system was in the end chosen as the most critical subsystem in the tapping carriage.

5.1.2 Identify critical components and failure modes

The hydraulic system is a complex system and it consists of many components. Due to delimitations, mentioned in *chapter 1.5.2 - Delimitations*, only 2-3 components would be selected to study further.

⊟HYDRAULIKKANLEGG TAPPEVOGN NR01 HYDEQ	⊞Annen utrustning Tillegg	7
	⊞Chassis / Førerhus Tillegg	3
	⊞Hydraulikk Akkumulator	5
	⊞Hydraulikk Foredelergear pustefilter	4
	⊞Hydraulikk Fremdriftspumpe	2
	⊞Hydraulikk Motorer	14
	⊞Hydraulikk Olje	10
	⊞Hydraulikk Pumpe	8
	⊞Hydraulikk Returfilter	5
	⊞Hydraulikk Rør	18
	⊞Hydraulikk Slanger	25
	⊞Hydraulikk Sylinder for fjæring	34
	⊞Hydraulikk Sylinder for løft	6
	⊞Hydraulikk Sylinder for støttelabber	9
	⊞Hydraulikk Sylinder for traversering	11
	⊞Hydraulikk Tillegg	21
	⊞Hydraulikk Ventiler	44
	⊞Motor Kompressor	1
	⊞Spesialutrusting Støttelabber	4

Figure 17: Clipboard showing the components in the chosen hydraulic subsystem

Figure 17 shows how many failures that are registered on the different components under the hydraulic subsystem. As explained in *chapter 3.1 Step 1: Identify subsystem and components*, the idea was to move forward with the components that were most critical, meaning having the most failures. To identify these components their failures was divided into the categories Changed or Fixed and counted, as were done for the subsystems in *chapter 5.1.1 Identify critical* subsystem. The result is presented in Table 2 below.

Table 2: Number of failures registered on the components in the hydraulic system

Components	**HYDRAULIKKANLEGG TAPPEVOGN NR01 HYDEQ**		**TAPPEVOGN NR01 HYDEQ**		**Total**	
	Skiftet	Fikset	Skiftet	Fikset	Skiftet	Fikset
Hydraulikk Akkumulator	2		3	1	5	1
Hydraulikk Foredelergear pustefilter		1			0	1
Hydraulikk Fremdriftspumpe		1	6	3	6	
Hydraulikk Motorer	2		3	2	5	2
Hydraulikk Olje	2	2	3	1	5	3
Hydraulikk Pumpe	1		7		8	0
Hydraulikk Returfilter		1			0	1
Hydraulikk Rør	5	1	9	2	14	3
Hydraulikk Slanger	7	1	18	2	25	3
Hydraulikk Sylinder for fjæring	11	1	7	2	18	3
Hydraulikk Sylinder for løft	1			3	1	3
Hydraulikk Sylinder for lokk			1	2	1	2
Hydraulikk Sylinder for støttelabber	2		8		10	0
Hydraulikk Sylinder for traversering	5		1	1	6	1
Hydraulikk Tillegg	1	4	8	7	9	11
Hydraulikk Ventiler	13	1	3	1	16	2
Hydraulikk Manometer Høytrykk 190-220bar			1		1	0
Hydraulikk Nødkjøringspumpe				1	0	1
Hydraulikk Tank			2	1	2	1
Hydraulikk Vacuum			1	1	1	1
Hydraulikkanlegg			15	1	15	1

As seen from Table 2 hose, pipes and cylinder are the three most critical components based on how many maintenance operations that are registered. However, after discussions with Larsen it was decided to choose three consecutive components instead of the components with the most logged failures. The components that were chosen ended up being *Fremdriftpumpe, Motor og Fremdriftsslange* (propulsion pump, engine and propulsion hose). This decision was made based on Larsen's knowledge about the tapping carriages and the fact that when failures occur in some components, they are often connected to failures in nearby or connecting components.

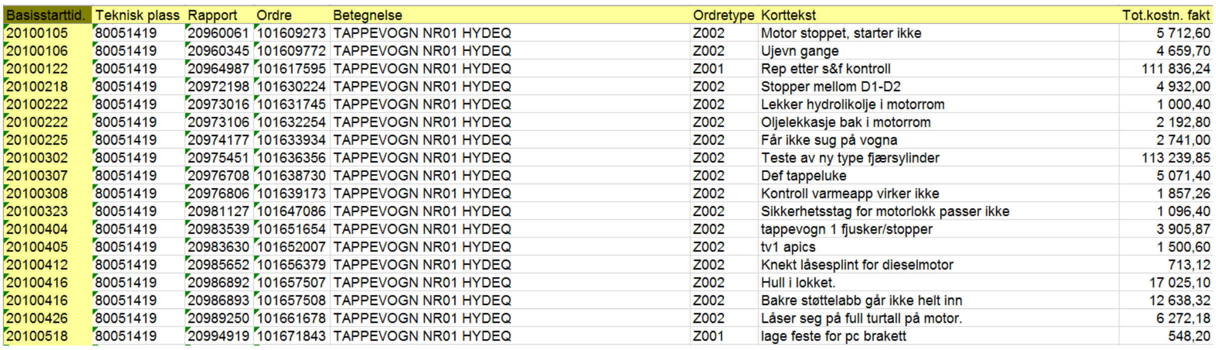
Table 2 also shows failures collected from two different units with data. ‘HYDRAULIKKANLEGG TAPPEVOGN NR01 HYDEQ’ is showing all the failures registered under the hydraulic subsystem, while ‘TAPPEVOGN NR01 HYDEQ’ shows the failures registered in the ‘collecting’ units for failure on the tapping carriage. The failures in this collection unit are not registered correct by the ones logging the failure data into SAP, so the failures ended up in the collection unit and not registered on the specific component. The column to the right shows a total of failures from the two units, divided into Changed/Skiftet and Fixed/Fikset.

As mentioned in *chapter 5.1.1 Identify critical* subsystem, Hydro don’t register failure mode when logging the maintenance operation into SAP, so failure mode could not be identified in this thesis, and the analysation had to continue without it.

5.2 Determine maintenance impact

The next step in the data analysis process was to analyse the costs connected to the maintenance of the selected components and determine the maintenance impact in term of service and spare part costs. Cost data showing the maintenance costs for the tapping carriage number 1 were collected from SAP and converted to Excel by Larsen. ‘Kostander Materiell’ and ‘Kostander ordre’ was the two excel sheets that were used.

‘Kostander Materiell’ showed the cost of the material that were used in the maintenance of the components, while ‘Kostander ordre’ showed the total cost of the whole maintenance operation – including the material cost.



Basisstarttid.	Teknisk plass	Rapport	Ordre	Betegnelse	Ordretype	Korttekst	Tot.kostn. fakt
20100105	80051419	20960061	101609273	TAPPEVOGN NR01 HYDEQ	Z002	Motor stoppet, starter ikke	5 712,60
20100106	80051419	20960345	101609772	TAPPEVOGN NR01 HYDEQ	Z002	Ujevn gange	4 659,70
20100122	80051419	20964987	101617595	TAPPEVOGN NR01 HYDEQ	Z001	Rep etter s&f kontroll	111 836,24
20100218	80051419	20972198	101630224	TAPPEVOGN NR01 HYDEQ	Z002	Stopper mellom D1-D2	4 932,00
20100222	80051419	20973016	101631745	TAPPEVOGN NR01 HYDEQ	Z002	Lekker hydrolikolje i motorrom	1 000,40
20100222	80051419	20973106	101632254	TAPPEVOGN NR01 HYDEQ	Z002	Oljelekkasje bak i motorrom	2 192,80
20100225	80051419	20974177	101633934	TAPPEVOGN NR01 HYDEQ	Z002	Får ikke sug på vogna	2 741,00
20100302	80051419	20975451	101636356	TAPPEVOGN NR01 HYDEQ	Z002	Teste av ny type fjærsylinder	113 239,85
20100307	80051419	20976708	101638730	TAPPEVOGN NR01 HYDEQ	Z002	Def tappeluke	5 071,40
20100308	80051419	20976806	101639173	TAPPEVOGN NR01 HYDEQ	Z002	Kontroll varmeapp virker ikke	1 857,26
20100323	80051419	20981127	101647086	TAPPEVOGN NR01 HYDEQ	Z002	Sikkerhetsstag for motorlokk passer ikke	1 096,40
20100404	80051419	20983539	101651654	TAPPEVOGN NR01 HYDEQ	Z002	tappevogn 1 fjusker/stopper	3 905,87
20100405	80051419	20983630	101652007	TAPPEVOGN NR01 HYDEQ	Z002	tv1 apics	1 500,60
20100412	80051419	20985652	101656379	TAPPEVOGN NR01 HYDEQ	Z002	Knekt låsesplint for dieselmotor	713,12
20100416	80051419	20986892	101657507	TAPPEVOGN NR01 HYDEQ	Z002	Hull i lokket.	17 025,10
20100416	80051419	20986893	101657508	TAPPEVOGN NR01 HYDEQ	Z002	Bakre støttelabb går ikke helt inn	12 638,32
20100426	80051419	20989250	101661678	TAPPEVOGN NR01 HYDEQ	Z002	Låser seg på full turtall på motor.	6 272,18
20100518	80051419	20994919	101671843	TAPPEVOGN NR01 HYDEQ	Z001	lage feste for pc brakett	548,20

Figure 18: Clipboard of cost data collected from SAP, showing cost connected to orders

Figure 18 shows a snapshot from the excel sheet ‘Kostander ordre’ and display some of the workorders on tapping carriage number 1, and the connected costs.

This excel sheet was used in combination with ‘Feildata TV1’ to find the cost connected to the maintenance of the selected component. First the maintenance operations including the order number were found in ‘Feildata TV1’, then the order number were used to track the correct maintenance costs in the excel sheet ‘Kostander ordre’. These costs where then evaluated and used to make a graph of the maintenance cost connected to each of the selected components.

There were made 3 models showing the maintenance cost for each component, one for costs regarding the category Changed, one for the Fixed category and one for the two combined. These three models can be seen in Figure 19, Figure 20 and Figure 21.

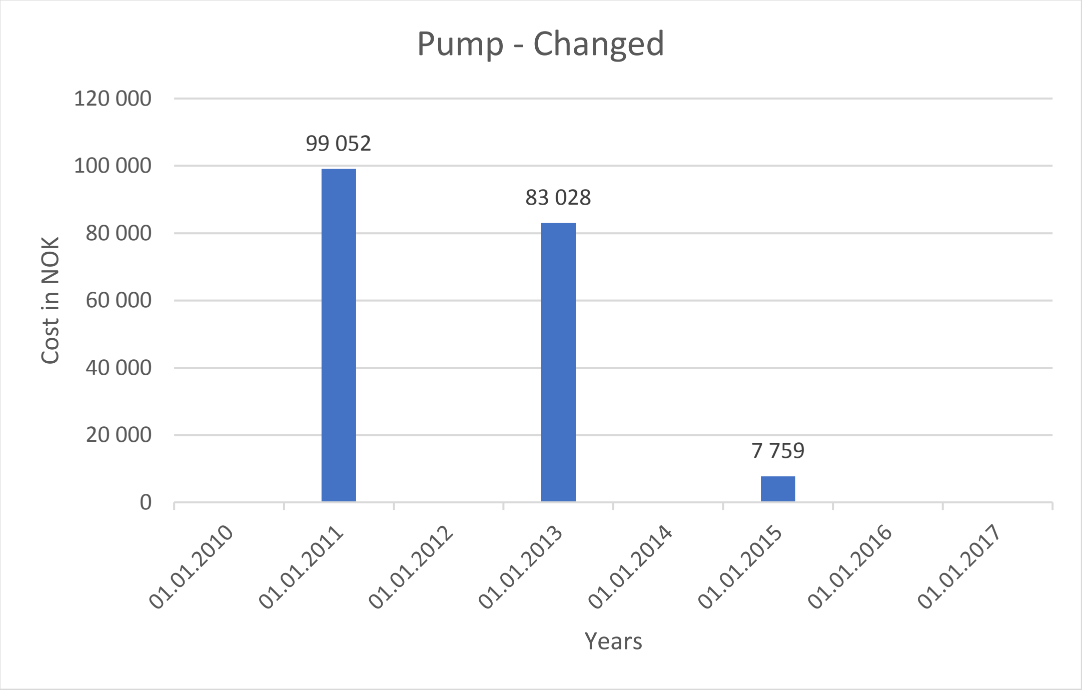


Figure 19: Maintenance cost for the pump, changed

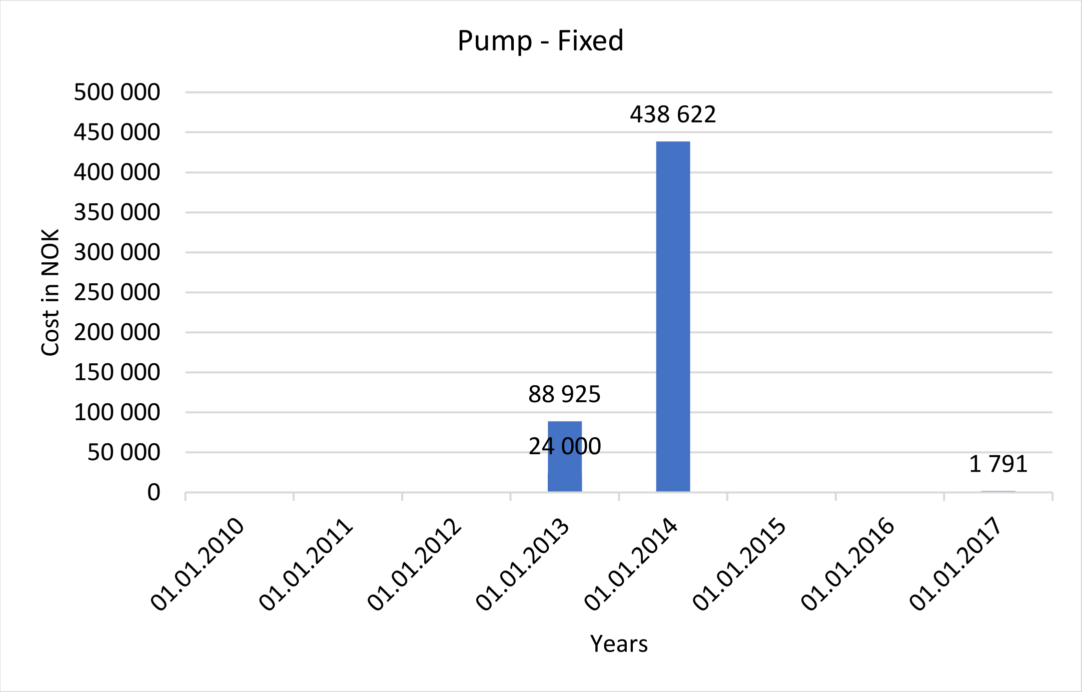


Figure 20: Maintenance cost for the pump, fixed

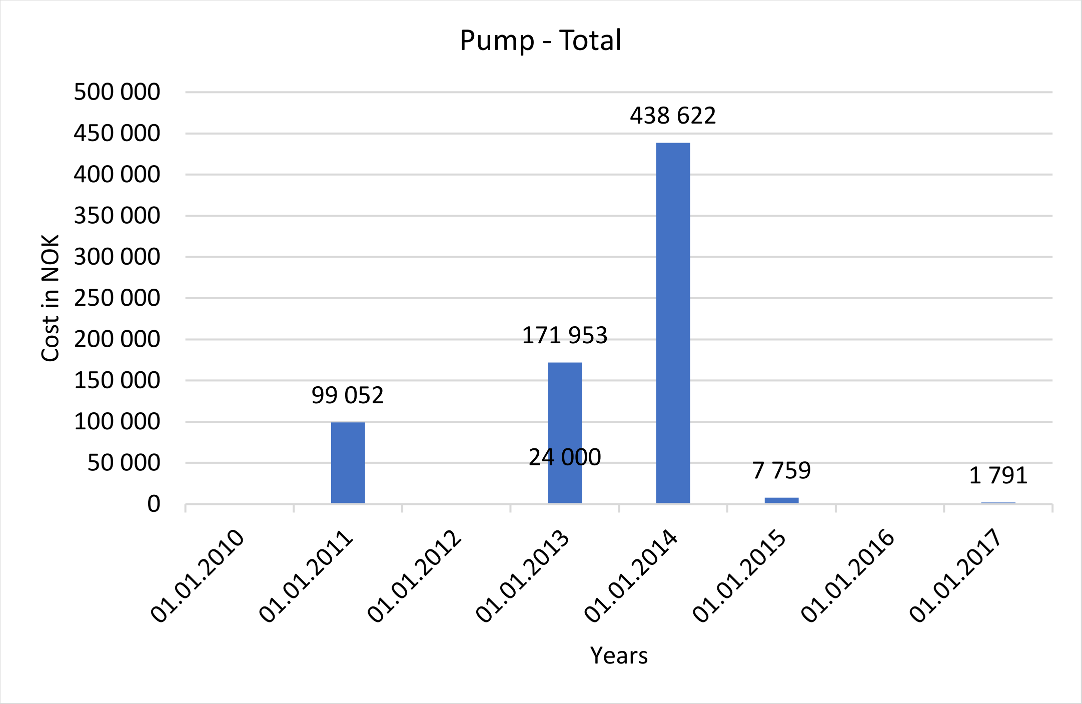


Figure 21: Maintenance cost for the pump, total

As seen in Figure 21, there have been a high maintenance cost for the propulsion pump during the years 2011 to 2014. During these 4 years the maintenance cost was on a total of 730 000 NOK.

The same three models that were made for the pump, was also made for the engine, shown in Figure 22, Figure 23 and Figure 24.

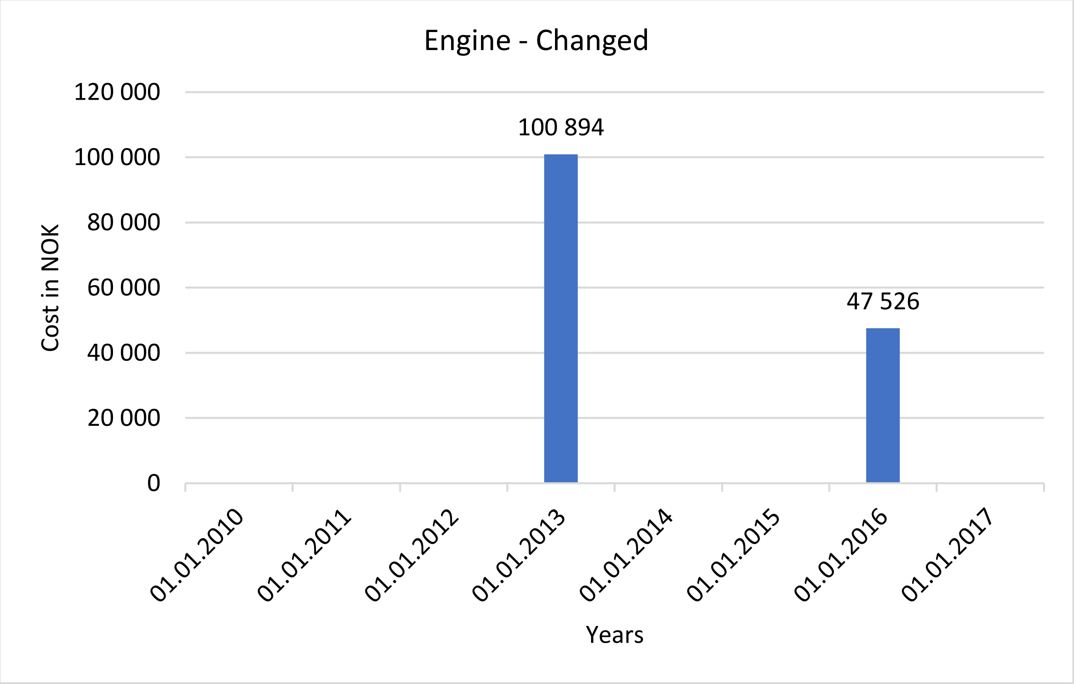


Figure 22: Maintenance cost for the engine, changed

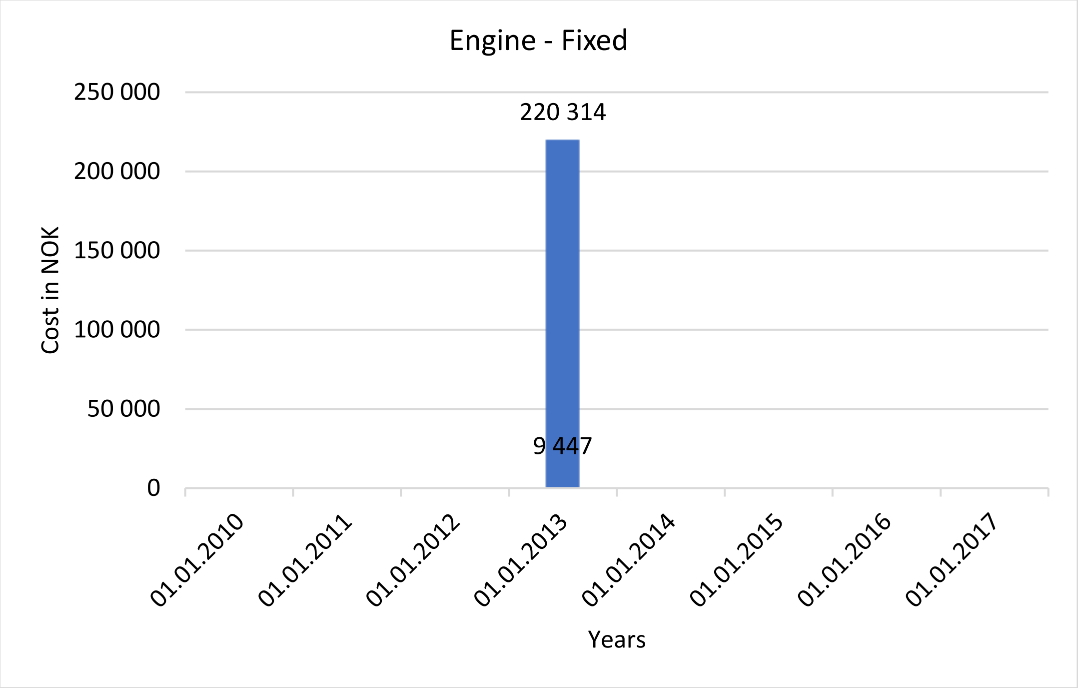


Figure 23: Maintenance cost for the engine, fixed

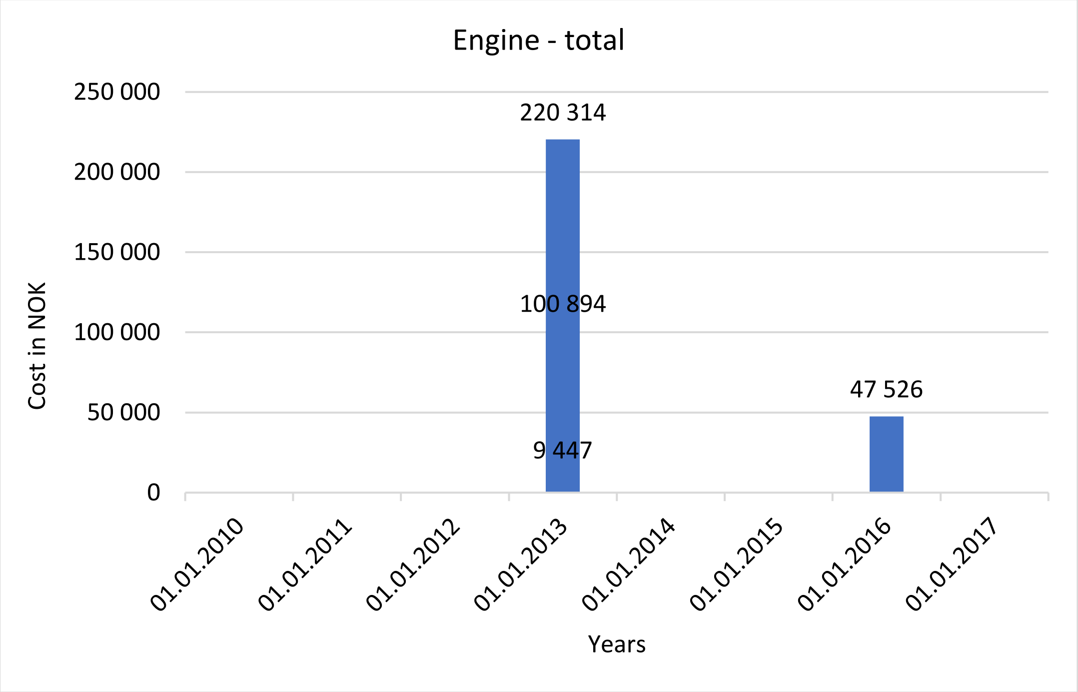


Figure 24: Maintenance cost for the engine, total

In addition to the pump, the engine has also had a high maintenance cost. As seen Figure 24 2013 stands out as a year with high expenditure, with a total of over 330000 NOK that year alone.

The next step in this analyzation was supposed to be evaluation of the maintenance operation and related cost to the propulsion hoses, but this data was not as easy to access. The prolusion hoses are not registered in SAP the same way as the other two components, and the maintenance of these hoses are also handled different. Since the third component required further and more comprehensive analyzation it was decided to continue without data about the propulsion hose.

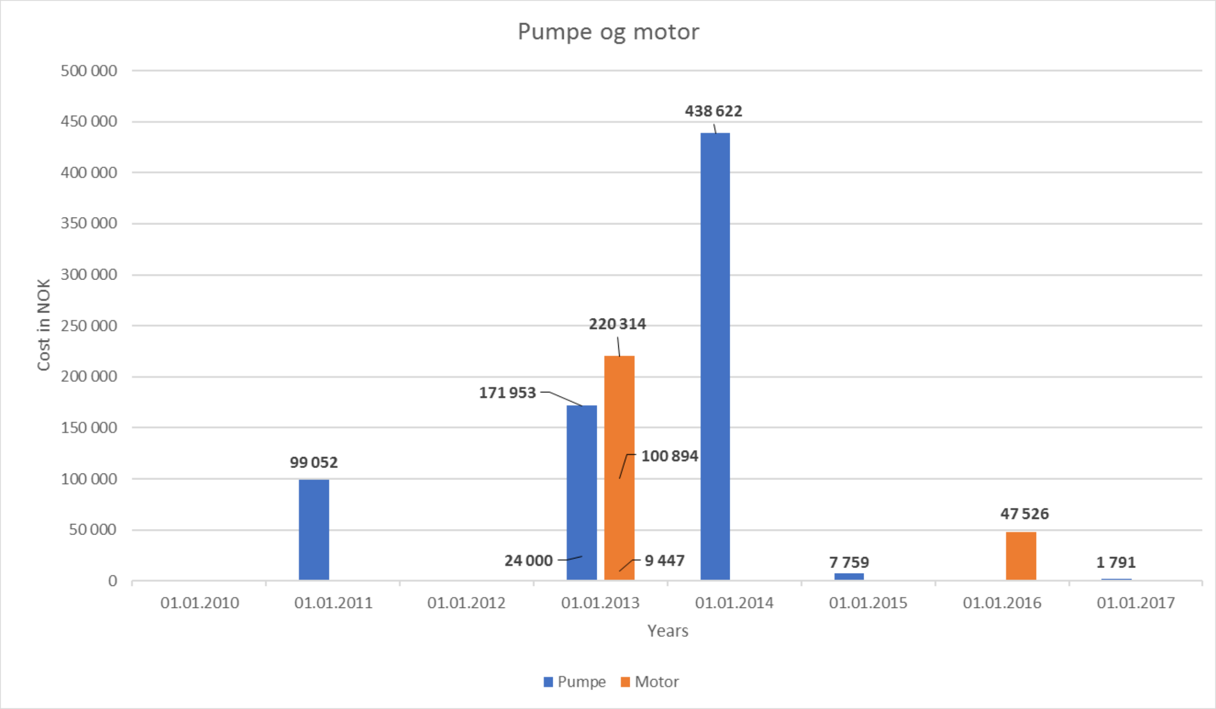


Figure 25: Maintenance cost for the pump and engine, from 2010 to 2017

Figure 25 shows a collection of all the maintenance operation, registered on both the propulsion pump and the engine in the hydraulic system. It also shows the associated cost and when the maintenance operations happened during the period from 2010 to 2017.

Since the reviewed data cover so many years of maintenance operation, it should be safe to say that it is representative to be repeated in the future.

5.3 Determine the real maintenance event timeline

After determining the maintenance cost for the components in the period 2010 to 2017 the next step was to develop a system dynamic model which would help with answering the research question. Before the model could be developed, a maintenance interval for the components based on the data analyzation had to be made. Since the analysed data covered a period of 8 years, and the tapping carriage that was used as a case study was 20 years old, it was reasonable to believe that the gathered maintenance data would help create a picture of the expected maintenance cost for the upcoming years.

Based on the total maintenance cost-models presented in *chapter 5.2*, Figure 21 and Figure 24, the author tried to establish a maintenance interval of lifetime for the relevant components.

5.3.1 Summary of the maintenance costs interval for the pump

As seen in Figure 21 the highest maintenance cost for the pump was in 2014 and was on about 440 000 NOK. This was the only time such an expensive maintenance operation was made on the pump, so determining if this cost would repeat itself and if so when it would be repeated, was difficult.

The other maintenance costs on the pump was not so high as the one in 2014, but still - summed up together they became a quite high cost. In 2011 there was a cost on a little under 100 000 NOK. Two years later, in 2013, there were a new big maintenance cost on a total of about 200 000 NOK which made it seem like there would be a rather big cost every second year. However, in 2015 and 2017 the maintenance costs on the pump were minimal, which rejected the assumption of a high maintenance cost every second year.

5.3.2 Summary of the maintenance costs interval for the engine

In the period from 2010 to 2017 there was only four maintenance operations done on the engine, three in 2013 and one in 2016, see Figure 24. Summed up, the cost for the three operations in 2013 was on 330 000 NOK, while the one in 2016 only was on a little under 50 000 NOK. From 2010 there went a little over 3 years before the first maintenance operation was needed. After the workover in 2013 there went 3 years to the next one in 2016.

Even though the cost in these two years was not close to be the same, there could be implied that there was an interval of three years between each maintenance operation needed on the engine.

5.3.3 Summary of interval for pump and engine

It was not easy to determine the interval of the maintenance operation and the associated cost based on the data that was gathered about the components. In best case, there could be made some assumptions, saying the maintenance operation for the engine will be repeated after three years. However, saying something concrete about the related costs was not so easy, but there could be made a simplification saying the cost would be the average of the total costs in 2013 and 2016. The average cost for these two years would then be 190 000 NOK.

When trying to evaluate the maintenance operations and the associated costs for the pump, the author came to the conclusion that there was no concrete repetition in the maintenance interval which showed a concrete connection to the costs, so there were no clear interval patterns to be made.

The lack of a clear pattern in the maintenance cost interval for both the pump and the engine, made it difficult to make a model and a simulation that would say something about the accumulated maintenance cost and interval the upcoming years.

5.4 System Dynamic Model

Even though a clear maintenance cost interval could not be made based on the data analyzation of the chosen components, the author decided to move forward with the system dynamic model.

The reason why it was decided to make the simulation and the model anyway, was to make a picture of how the accumulated global maintenance costs for the chosen components would develop over a period of 20 years. The model could be used to make decisions about what would be the best solution as the years passed, repair or replace, and answer if there was a big difference in having a global or a local maintenance perspective. Since the data analyzation did not provide sufficient basis for making a correct simulation and model, it was instead made some simplifications and assumptions so that a model in fact could be made.

This was done to show how the simulation and the model would work, and how it could be used if the correct data was entered. To see how the simulation was influenced by the raw data plotted in to the program, two scenarios were made.

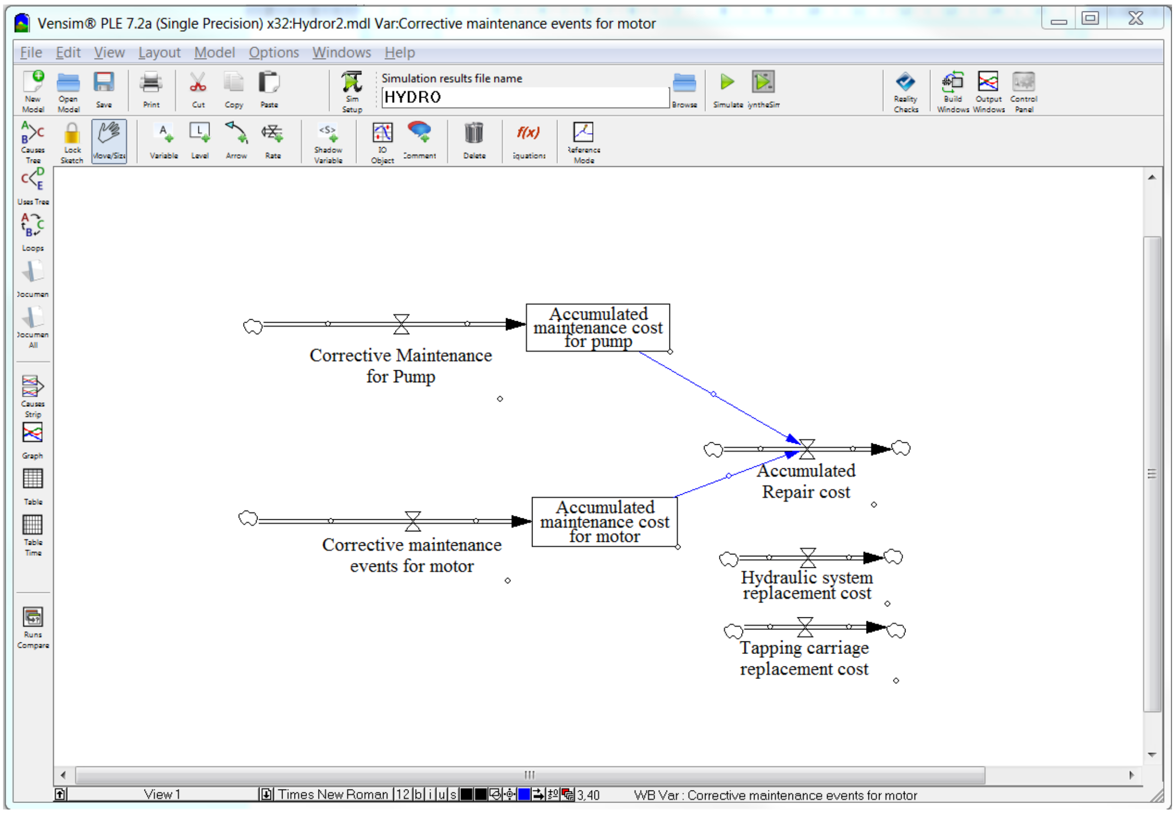


Figure 26: Input of data in the simulation program Vensim

Figure 26 is a snapshot from the simulation program Vensim, and shows how the information about the components and cost of new systems are plotted into Vensim and have an impact on accumulated repair cost.

The arrows (not the blue ones) in Figure 26 is the rates, and in a simulation model the equation added into the rates governs the direction that material can flow. The two boxes are levels or stocks, and the equation put into the rate (showed in Figure 27,Figure 28, Figure 29 and Figure 30) influence the levels. The two rates and levels linked to the two components, are then put into a new rate, which gives the accumulated repair cost.

(25)

5.4.1 Scenario 1

5.4.1.1 Pump:

As explained in chapter *5.3 Determine the real maintenance* event timeline, for the pump there was a repetition in maintenance operations every second year, but the costs was not equally distributed. In addition to these costs, there was a very high cost in 2014 that was not repeated neither before or after this year. So, the first scenario makes a simplification saying the maintenance cost for the pump could be divided into two intervals.

Interval 1:

Average of the maintenance costs for year 2011, 2013, 2015 and 2017 was divided between these years.

$$\frac{(99\,052 + (171\,953 + 24\,000) + 7\,759 + 1\,791)NOK}{4} = 76\,139\;NOK$$

$$76\,139\;NOK \approx 80\,000\;NOK$$

Start time: after 12 months

Maintenance duration: 1 month

After how long maintenance will be repeated: 23 months

Simulate for: 240 months

Interval 2:

The cost in 2014 was assumed to be repeated every 4 years, and rounded up to 440 000 NOK.

Start time: after 48 months

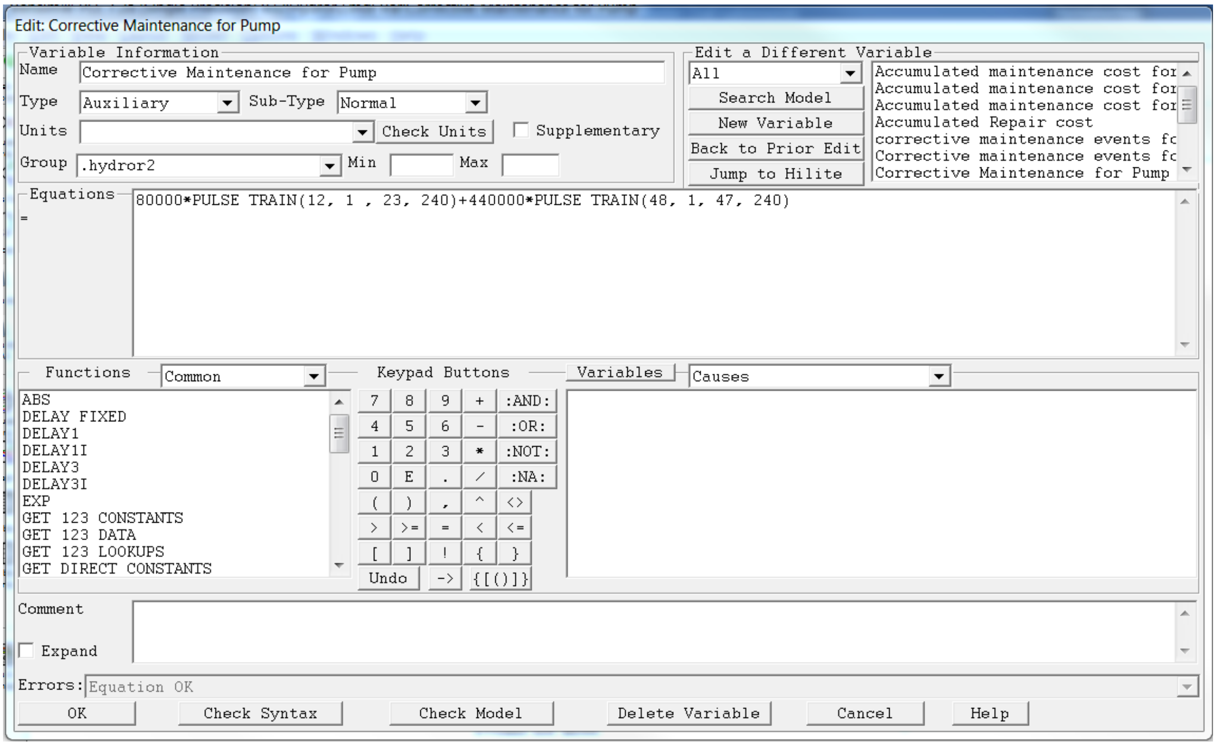
Maintenance duration: 1 month

After how long maintenance will be repeated: 47 months

Simulate for: 240 months

Input to Vensim:

$$80\,000 \cdot \mathit{Pulse\ Train}(12, 1, 23, 240) + 440\,000 \cdot \mathit{Pulse\ Train}(48, 1, 47, 240)$$


Edit: Corrective Maintenance for Pump

Name: Corrective Maintenance for Pump

Type: Auxiliary

Sub-Type: Normal

Group: .hydror2

Equations: 80000*PULSE TRAIN(12, 1 , 23, 240)+440000*PULSE TRAIN(48, 1, 47, 240)

Errors: Equation OK

Figure 27: Input of data about the pump to Vensim, scenario 1

Figure 27 is a snapshot from the simulation program Vensim and shows how the information about the pump is plotted into Vensim to make a simulation of the maintenance costs.

5.4.1.1 Engine:

As explained in chapter *5.3 Determine the real maintenance* event timeline, in best case there could be made an assumption that the maintenance interval for the engine will be repeated after three years. To establish a cost for this maintenance the simplification to find the average cost of the operations taking place in 2013 and 2016 was made.

$$\frac{\big((220\,314 + 100\,894 + 9447) + 47526\big)NOK}{2} = 189\,090\ NOK$$

$$189\,090\ NOK \approx 190\,000\ NOK$$

Start time: after 36 months

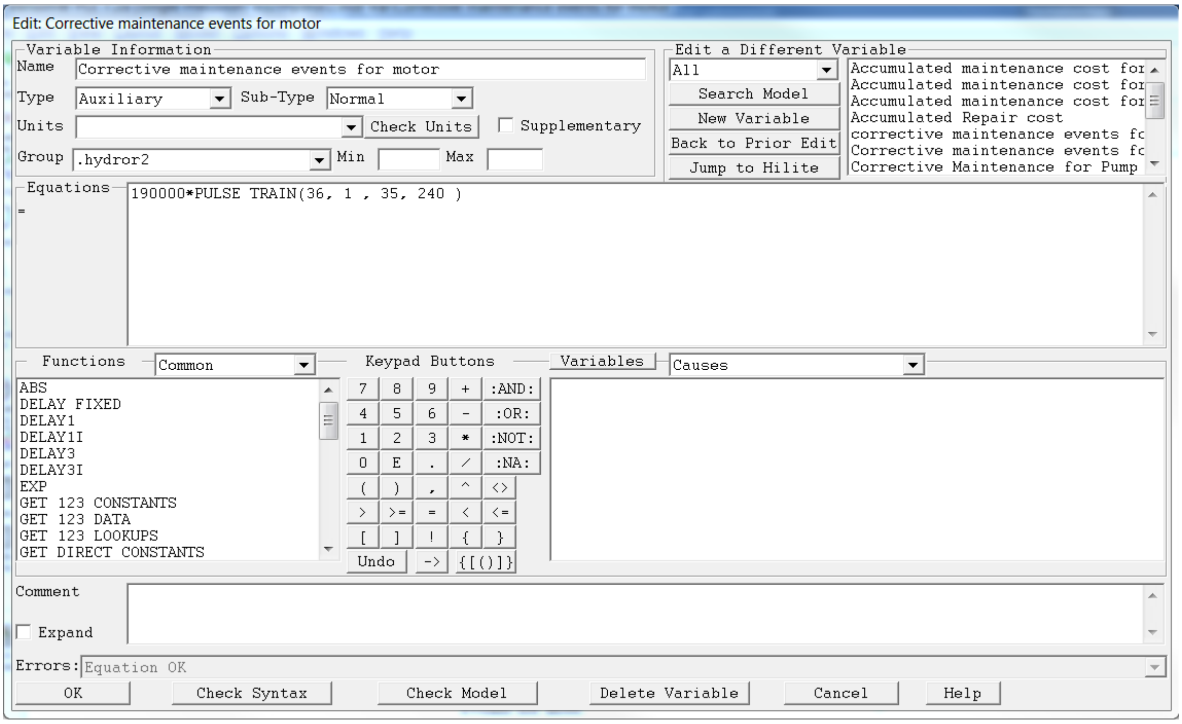
Maintenance duration: 1 month

After how long maintenance will be repeated: 35 months

Simulate for: 240 months

Input to Vensim:

$$190\,000 \cdot Pulse\ Train(36, 1, 35, 240)$$



Edit: Corrective maintenance events for motor

Name: Corrective maintenance events for motor

Type: Auxiliary

Sub-Type: Normal

Units:

☐ Supplementary

Group: .hydror2

Min:

Max:

Equations =

```
190000*PULSE TRAIN(36, 1 , 35, 240 )
```

Comment:

☐ Expand

Errors: Equation OK

Figure 28: Input of data about the engine to Vensim, scenario 1

Figure 28 is a snapshot from the simulation program Vensim, and shows how the information about the engine is plotted into Vensim to make a simulation of the maintenance costs.

5.4.2 Scenario 2

5.4.2.1 Pump:

Instead of dividing the maintenance cost into two intervals, this time another simplification was made. The big cost from 2014 was added to the average cost for 2011, 2013, 2015 and 2017. The reason why this simplification was made was based on input from Larsen and Rydland.

Most likely the cost on 440 000 NOK in 2014 was probably not only related to maintenance on the pump. This operation was in connection with an SF-control, Sikkerhet og Funkjson kontroll, where a lot of other components were maintained and checked as well as the pump. Before 2015 these SF-controls where logged in to SAP by registering the whole operation on one of the components that where maintained, and in this case that was the propulsion pump.

The average of the maintenance costs for year 2011, 2013, 2015 and 2017, including the cost from the SF control in 2014 was found by assuming maintenance operating would be repeated every second year.

$$\frac{(99\,052 + (171\,953 + 24\,000) + 7\,759 + 1\,791 + 438\,622)NOK}{4} = 185\,794\,NOK$$

$$185\,794\ NOK \approx 186\,000\,NOK$$

Start time: after 12 months

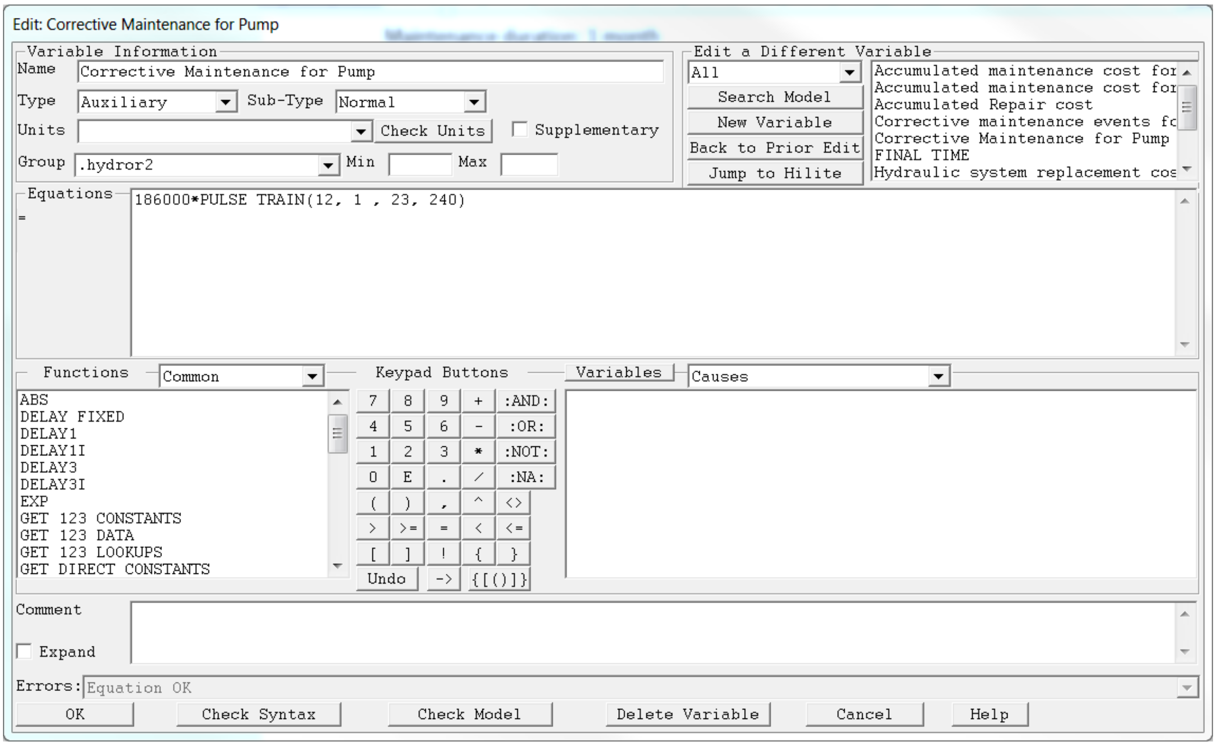
Maintenance duration: 1 month

After how long maintenance will be repeated: 23 months

Simulate for: 240 months

Input to Vensim:

$$186\,000 \cdot Pulse\ Train(12, 1, 23, 240)$$



Edit: Corrective Maintenance for Pump

Variable Information

Name: Corrective Maintenance for Pump

Type: Auxiliary

Sub-Type: Normal

Units:

☐ Supplementary

Group: .hydror2

Equations: = 186000*PULSE TRAIN(12, 1 , 23, 240)

Comment:

☐ Expand

Errors: Equation OK

Figure 29: Input of data about the pump to Vensim, scenario 2

Figure 29 is a snapshot from the simulation program Vensim, and shows how the information about the pump is plotted into Vensim to make a simulation of the maintenance costs.

5.4.2.2 Engine:

The same interval and simplification as sin scenario 1:

$$\frac{\big((220\,314 + 100\,894 + 9447) + 47526\big)NOK}{2} = 189\,090\ NOK$$

$$189\,090\ \ NOK \approx 190\,000\ NOK$$

Start time: after 36 months

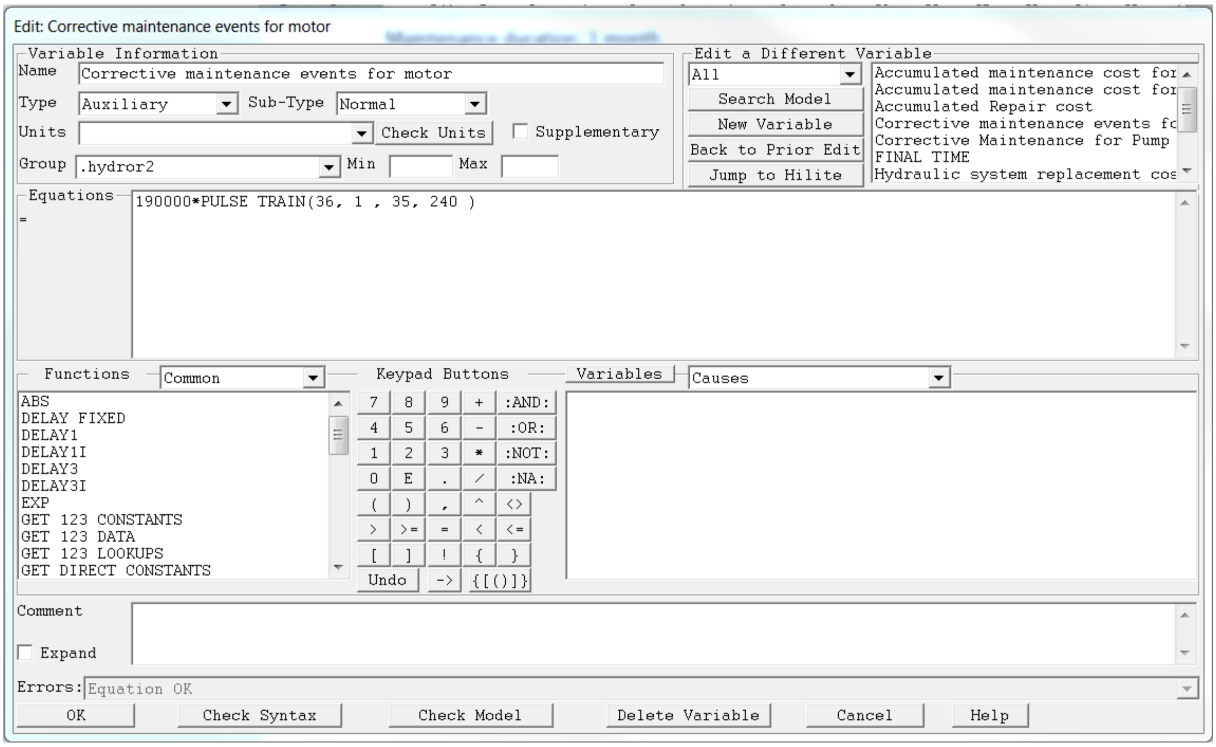
Maintenance duration: 1 month

After how long maintenance will be repeated: 35 months

Simulate for: 240 months

Input to Vensim:

$$190\,000 \cdot Pulse\ Train(36, 1, 35, 240)$$



Edit: Corrective maintenance events for motor

Name: Corrective maintenance events for motor

Type: Auxiliary

Sub-Type: Normal

Units:

☐ Supplementary

Group: .hydror2

Min:

Max:

Equations =

190000*PULSE TRAIN(36, 1 , 35, 240)

Comment:

☐ Expand

Errors: Equation OK

Figure 30: Input of data about the engine to Vensim, scenario 2

Figure 30 is a snapshot from the simulation program Vensim, and shows how the information about the engine is plotted into Vensim to make a simulation of the maintenance costs.

The result from the two different scenarios are presented in chapter *6 Results and discussion*.

6 Results and discussion

As explained in chapter *5.3 - Determine the real maintenance event timeline*, clear patterns of maintenance events was not perfectly recognized in the way that allows us to simulate it. However, some assumptions and simplification were made to make different scenarios in the attempt to show how the simulation works. The simulation would create a picture of how the accumulated maintenance costs for the components (global focus) would develop if the simulation was based on only real data. This is what chapter 6 is about, showing the result of the different scenarios from chapter 5, including a discussion of the result.

6.1 Result of scenario 1

In scenario 1 the simulation was based on two repeating intervals for the pump, every second and every fourth year, and one interval for the engine repeating every third year.

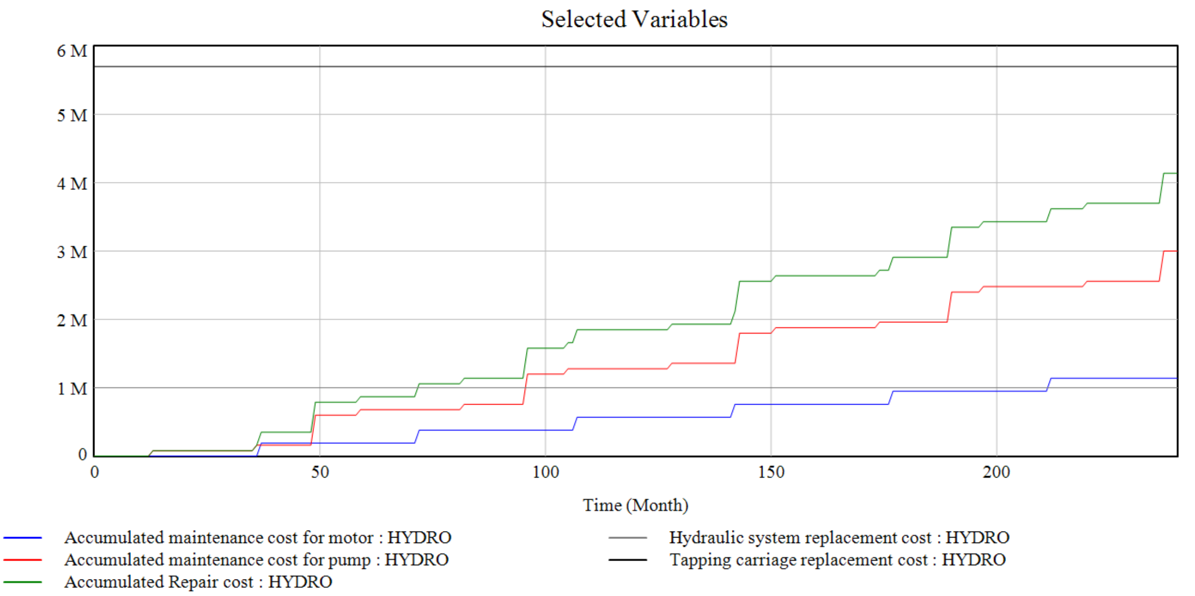


Figure 31: Simulated model of scenario 1 from Vensim

Figure 31 is a snapshot from the simulation program Vensim, it shows the result of the simulation for scenario 1, and how the accumulated cost develops over the next 20 years. The X-axis shows time in months, while the Y-axis show cost in million NOK. The blue line is the accumulated maintenance cost for the engine, the red is for the pump and the green is a combination of those two – *the accumulated global maintenance cost*. At 1 million there is a line marking the cost of a new hydraulic system, and just beneath 6 million (5.7 million) there is a line marking the cost of a whole new tapping carriage.

As seen from Figure 31, the green line crosses the grey ‘1 million line’ after about 70 months or approximately 6 years. This means that when 6 years have passed, the cost of continuing maintenance on the pump and engine in the hydraulic system exceeds the price of buying a brand new hydraulic system.

Although this simulation only takes two components into consideration when simulating for the accumulated maintenance cost the next 20 years, the end cost is quite high. Reaching 240 months, or 20 years, the accumulated maintenance cost for only two components are simulated to be over 4 million NOK.

6.2 Result of scenario 2

In scenario 2 the simulation was based on a repeating interval every second year for the pump, and an interval for the engine repeating every third year.

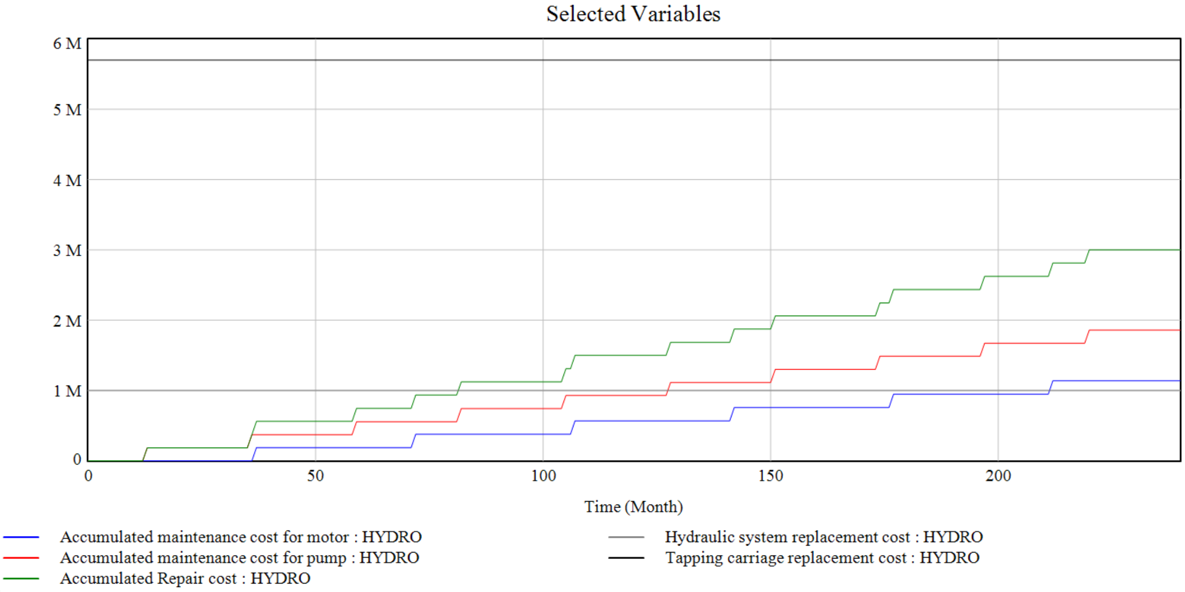


Figure 32: Simulated model of scenario 2 from Vensim

Figure 32 is a snapshot from the simulation program Vensim, it shows the result of the simulation to scenario 2, and just as Figure 31 it shows how the accumulated cost develops over the next 20 years. The explanations about the meanings of the different graphs are the same as explained in scenario 1, the meaning of the different lines are also explained in the figure.

In scenario 2 the green line crosses the grey ‘1 million line’ after about 80 months which is a little under 7 years, not very far from scenario 1 where the crossing of this line took place after approximately 6 years. However, the end cost in scenario 2 is over 1 million NOK lower than in scenario 1. The end cost for scenario 2 is at 3 million NOK and still very high, but remarkably lower than in scenario 1 which is at over 4 million NOK.

6.3 Model and result verification and validation

After studying, reviewing and analysing several excel sheets, reading reports, counting endless failures and making a lot of tables and graphs, the data analyzation was finished. During the process there have been some issues, some setbacks and some delimitations, while working with the raw data that was taken out of SAP to be used for analyzation.

First of all, the author had no experience with SAP. To limit the workload and being able to keep within the timeframe, learning SAP was not a priority. Supervisor at HAK, Larsen, provided the author with the data that was needed and helped with the understanding of how the material should be read and used in the analyzation.

Delimitations in this context could be:

- Misunderstandings
- Bad communications between the student (the author) and supervisor
- Assumptions made by the student or the supervisor, about the others knowledge.

Errors could also have occurred when the student reviewed and analysed the data, missing a report, forgetting a step, reading or plotting the wrong numbers etc. In other words, basic human error is most definitely a source to error.

Another possible contribution to delimitation and errors is errors in the raw data collected from SAP. As mentioned in *chapter 5.1.1 Identify critical* subsystem, there exists an collection unit where undefined failures are placed. The reason this collection unit exist, is because when the failure was reported and registered into SAP the reports/orders was not always linked up to the correct system or subsystem. While looking through the extensive spreadsheets some of these misplaced reports was discovered. There was spent a lot of time and effort trying to locate misplaced reports that was relevant to the studied case, but one cannot be sure that all of them was discovered.

Larsen and Rydland, managers at maintenance department, also provided information in the last meeting, that maybe should have been considered earlier. In addition to the cost data provided from SAP, it is possible that there are maintenance costs registered another way. This is because some maintenance operations are later transmitted to a project and payed for with Capex funds. If this is the case with any of the analysed components, these costs have not been reviewed. Capex is short for capital expenditure, it is funds used by a company to acquire or upgrade physical assets for example, machinery, buildings, but also the original equipment, spare parts and so on (26).

In summary, the managers think that the data analyzation, simulation and the developed dynamic model is promising in supporting the equipment replacement decision making. If the rest of the systems failure data and associated costs was analysed and put into the simulated model, it could be used to support decision making regarding equipment replacement.

6.4 Discussion

The two scenarios were made to show how just a slightly different input to the simulation program, could influence the simulated model and give different basis for decision making.

As mentioned in chapter 6.1 and 6.2, the end cost after 20 years was quite high for both scenario 1 and 2, considering that the simulation was only based on two components. Scenario 2 took one year longer than scenario 1 to reach the crossing point at the ‘1 million line’ and as explained earlier scenario 2 was also 1 million NOK lower in end cost after 20 years than scenario 1.

For HAK to get a more real and useable result as well as a tool to use in decision making, all the components in the tapping carriage must be analysed and plotted into Vensim to be part of the simulation. Due to different delimitations, explained in *chapter 1.5.2*, only two components were analysed in this case study. One of the reasons it was hard to make concrete maintenance intervals based on the data analysation, was that there were only two components to evaluate. If several components where analysed, finding a pattern in the maintenance interval may had been easier, and making a more concrete and usable simulation would also be more achievable.

This kind of simulation and dynamic model was made to be able to answer some of the key questions in this master thesis, such as should there be a global of local focus when different maintenance options are being considered, and how to know when to repair vs when to replace.

Even though the dynamic model made in Vensim was based on some simplifications and assumptions, and concrete results and recommendations cannot be made, the failure data and the maintenance cost were based on real maintenance data from SAP. When analysing the maintenance cost for the two components it was not easy to find a pattern for how often the maintenance operation would be repeated, but other usable information occurred when the data was reviewed.

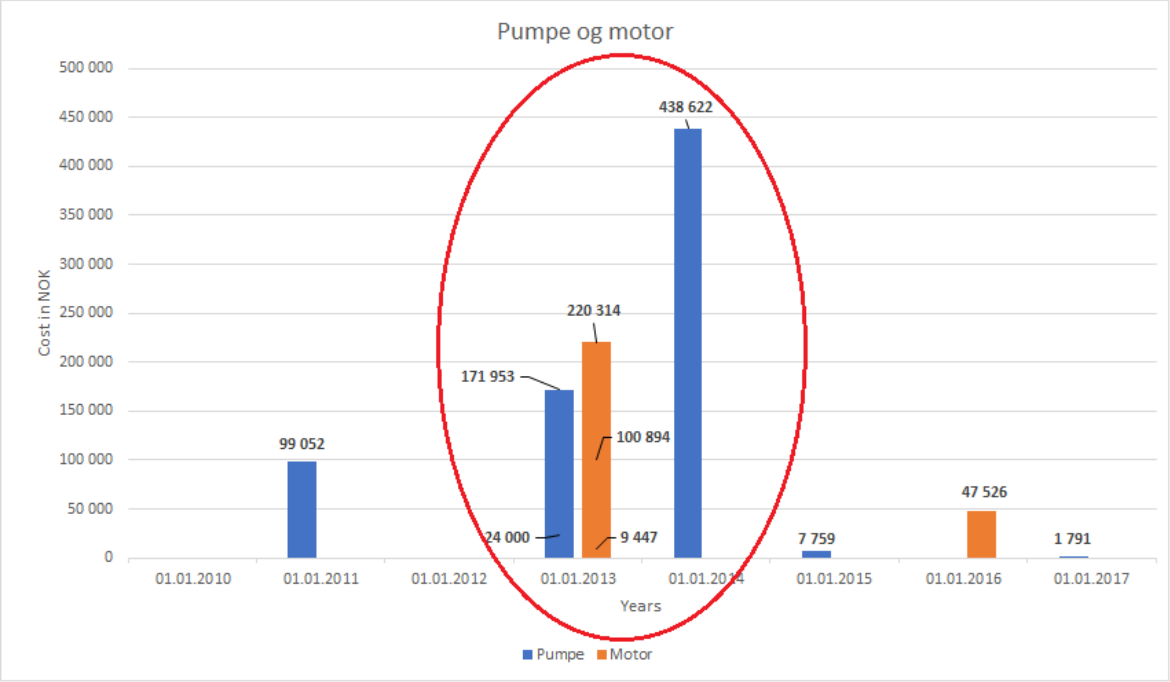


Figure 33: Maintenance cost for the pump and engine, with focus on 2013-2014

Figure 33 shows the maintenance operations done on the pump and engine in the hydraulic system, and the associated costs for each operation. Even though a repeating interval was not clearly found, as seen from this figure the maintenance cost on both the pump and engine was quite high in the period 2013-2014. In fact, the total sum during these two years was 965 230 NOK. As seen from Table 3, the price for a new hydraulic system is only a little higher than the total maintenance costs that took place in 2013 and 2014.

Table 3: Different costs

Maintenance pump + engine in 2013 and 2014	965 230 NOK
New Hydraulic system	1 000 000 NOK
New tapping carriage	5 700 000 NOK

Instead of continuing with repairs of the components, replacing the whole hydraulic system in the tapping carriage should have been considered. Replacing the old hydraulic system with a brand new would in this case be less expensive than continuing with the repairs, even when only two of the components in the hydraulic system is considered. This supports the theory in the hypothesis saying that by switching to a global maintenance policy, there can be a cut in costs in the long run, and it will be easier to make the right decisions regarding repair or replace components vs replacement of the whole system or subsystem.

When only looking at one component at the time it can be hard to make the decision about repair vs replace, but as seen in this case when two components where evaluated with a global focus the decision became much clearer. Why pay almost 1 000 000 NOK to repair two components when you can get a brand new subsystem for the same price?

7 Conclusions and recommendations

This chapter sums up the results in the thesis, gives a conclusion and try to come with some recommendations for HAK to consider for further development.

7.1 Conclusion

The aim of this thesis is to analyse historical maintenance data from a critical asset within the aluminium industry and utilize the results to develop a model that would visualize and support maintenance decisions e.g. repair vs replace. The developed model could reasonably provide an answer to the research question and the hypothesis, at least at subsystem level. We were hoping to reach a reasonable result at system level, but due to time and resource limitations in the case study, this was not possible. However, the model is scalable where the process can be expanded to cover all components within the whole system.

As showed Figure 33 and Table 3 in *chapter 6.4 - Discussion*, the cost for maintaining the two components in 2013 and 2014 was approximately the same as replacing the whole subsystem. This answers the research question from *chapter 1.3.1*, that the data is analysed and visualized in a way that "supports the maintenance decision to replace the subsystem instead of continuing with repairing each component". So firstly, a global perspective where the whole subsystem is considered would be a better maintenance policy, than a local focus where only the condition of one component at the time is considered. One effect of this maintenance optimizations is the potential of cut in costs over time. Also, by switching to a global focus HAK would get a better overview of the condition and asset value to the whole system.

Second, the models made from the simulations in Vensim, works like a decision-making tool when, e.g. decisions regarding replacement of components vs replacement of the whole (sub)system needs to be made. Figure 31 and Figure 32 in chapter 6, shows the accumulated cost for 20 years, and one can use these models to make decisions based on the cost of continuing with repair at a specific point in the systems lifetime, or consider replacing the whole (sub)system. Altogether this dynamic model would help HAK to make the right decision.

The predictive model illustrates how to utilize the collected maintenance data in order to learn and perform predictive analytics. This model emphasis the need to have integrated data collection system so that required inputs can be fed into the predictive model. The developed model was effective in providing two issues: (1) an automated process to illustrate and update the maintenance event timeline and accumulated cost, (2) an automated way to predict the future potential repair cost of each single component.

Third, this study show that data quality is significant to predict potential scenarios and support the decision-making process regarding equipment replacement. High quality data increase the reliability and validity of using this data to learn and predict future patterns and maintenance strategies. The industrial data that has been collected in this case study can in some way be characterized as incomplete, imprecise and a bit unstructured. Failure mode is not registered, costs are registered on the complete order instead of on the specific component and some of the failures are not logged in the correct location. These issues reduce the reliability and validity of the simulation model and the opportunity of using this data to learn and predict future patterns.

7.2 Recommendations

HAK is a big company with a lot of critical systems and equipment that they depend on every day in the aluminium production process. This is why I would recommend implementing some changes regarding their maintenance operations and its interface.

To analyse the maintenance data that were collected from SAP, there were used a tremendous amount of hours. To be able to make analysis based on the maintenance data, some changes should be made. First it needs to be established which analysation and results that wish to be achieved, and what questions they want answered. Then the 'logging of data' routines needs to be changed so that all relevant information that is needed to do the analysation, is reported the correct way in SAP. If the data is logged the correct way, it would be able to extract automatic reports and analysations when needed. It is recommended that it is established a smart user interface to report the related data to be implemented in order to ensure the completeness of data, avoid errors and guarantee the cost tractability at component level. It may be some extra work logging the information, but the job of analysing the data would be a lot easier and less time consuming. This probably also mean that using the analysis as a decision-making tool, when making decisions regarding maintenance would be much easier. It would also help HAK keep an optimized, effective and efficient maintenance policy.

To be able to do the simulation and make the dynamic model in this case study, the maintenance timeline needed to be generated. This was manually done by determining when the failures happened, the associated costs, costs of spare parts and time to repair. If all this information is available, any predictive tool e.g. Vensim can draw the maintenance timeline and estimate the future patterns. Vensim could be connected to SAP and collect the information automatically.

In the future HAK can use the simulated Vensim model as a basis for further development. This could be done by considering more components, upgrading the maintenance interval over the time and then putting this information into Vensim. To make the analysation part easier my recommendations for further development starts with improving logging routines and adding some information about the maintenance reports into SAP, such as:

- Failure event date and failure repair date.
- A list of all failure modes, where the once that are fixed is marked in a checkbox.
- A connecting table to the failure modes, where cost of service, spare parts, time used to repair, and failure cause would be reported.
- To ensure that all required data is reported some kind of control system should be in place, to notify if it is not reported the correct way.
- The selected predictive tool (in this case study being Vensim) should be connected to SAP to receive the reported data from the maintenance operation. Vensim could then use the data to draw a timeline for each failure mode and update the simulation and dynamic model continuously. Then the data related to failure causes can be transferred

into an RCM program (Reliability Centered Maintenance), where appropriate maintenance actions are selected, e.g. how and when to inspect the system and when to perform the recommended maintenance, how to detect failures and how to keep the system functioning (1).

At last I would recommend a change in how to mark the breakdown of the systems. Every equipment and system at HAK has a number register on it, called ‘Teknisk Plass’. Now all the subsystems and components in a system is register under the same number. If this number were divided to component level, it would be easier to sort between the failures of the different components and much easier to perform analysis based on the maintenance data.

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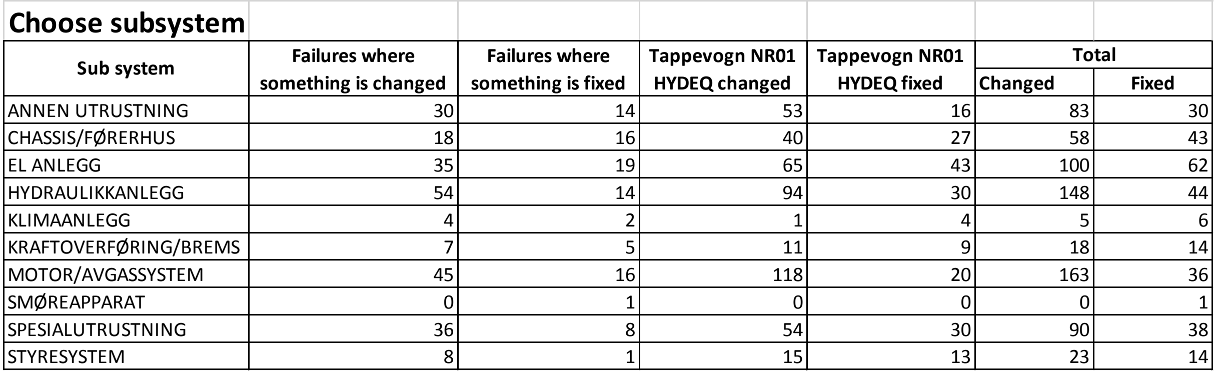
Appendix

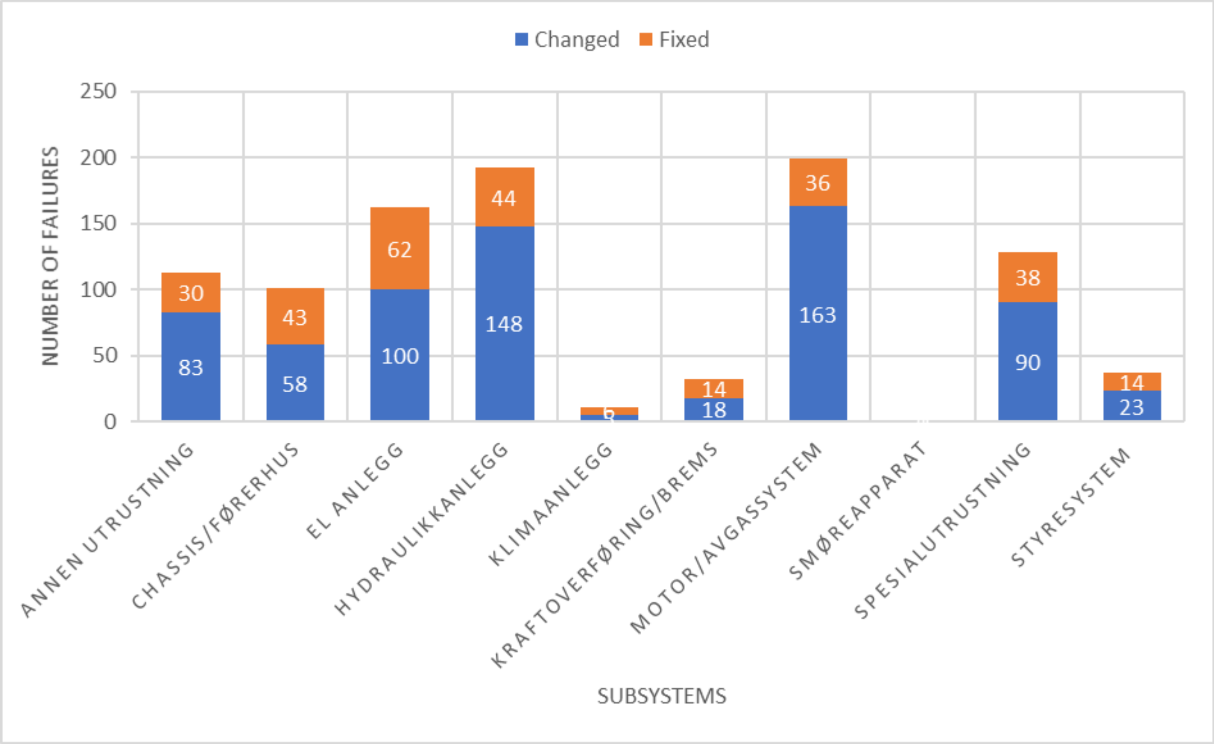
- Appendix A: Contains snapshots from the excel document that was used during the thesis to review data and analysing during the case study.
- Appendix B: Contains a snapshot of a maintenance checklist belonging to the tapping carriages.
- Appendix C: Contains Interview with Tor Magne Rydland

Appendix A:



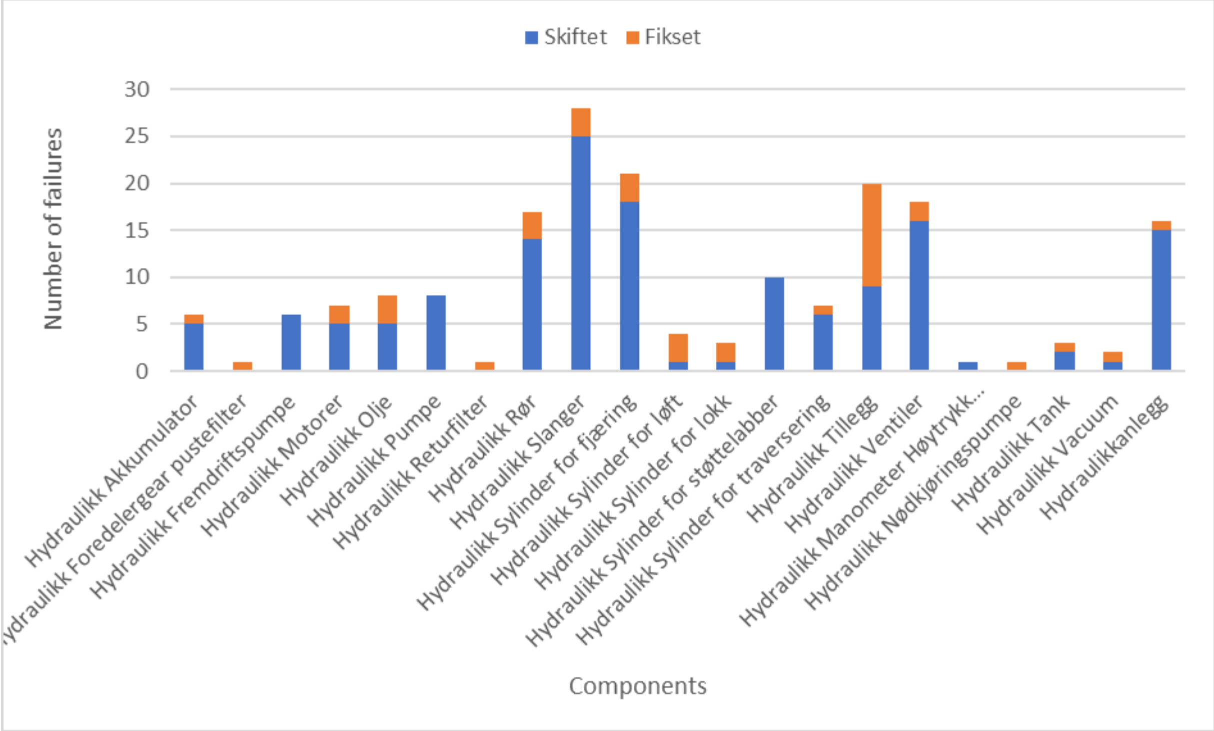
Choose subsystem

Sub system	Failures where something is changed	Failures where something is fixed	Tappevogn NR01 HYDEQ changed	Tappevogn NR01 HYDEQ fixed	Total	
					Changed	Fixed
ANNEN UTRUSTNING	30	14	53	16	83	30
CHASSIS/FØRERHUS	18	16	40	27	58	43
EL ANLEGG	35	19	65	43	100	62
HYDRAULIKKANLEGG	54	14	94	30	148	44
KLIMAANLEGG	4	2	1	4	5	6
KRAFTOVERFØRING/BREMS	7	5	11	9	18	14
MOTOR/AVGASSYSTEM	45	16	118	20	163	36
SMØREAPPARAT	0	1	0	0	0	1
SPESIALUTRUSTNING	36	8	54	30	90	38
STYRESYSTEM	8	1	15	13	23	14



Choose component

Components	HYDRAULIKKANLEGG TAPPEVOGN NR01 HYDEQ		TAPPEVOGN NR01 HYDEQ		Total	
	Skiftet	Fikset	Skiftet	Fikset	Skiftet	Fikset
Hydraulikk Akkumulator	2		3	1	5	1
Hydraulikk Foredelergear pustefilter		1			0	1
Hydraulikk Fremdriftspumpe		1	6	3	6	
Hydraulikk Motorer	2		3	2	5	2
Hydraulikk Olje	2	2	3	1	5	3
Hydraulikk Pumpe	1		7		8	0
Hydraulikk Returfilter		1			0	1
Hydraulikk Rør	5	1	9	2	14	3
Hydraulikk Slanger	7	1	18	2	25	3
Hydraulikk Sylinder for fjæring	11	1	7	2	18	3
Hydraulikk Sylinder for løft	1			3	1	3
Hydraulikk Sylinder for lokk			1	2	1	2
Hydraulikk Sylinder for støttelabber	2		8		10	0
Hydraulikk Sylinder for traversering	5		1	1	6	1
Hydraulikk Tillegg	1	4	8	7	9	11
Hydraulikk Ventiler	13	1	3	1	16	2
Hydraulikk Manometer Høytrykk 190-220bar			1		1	0
Hydraulikk Nødkjøringspumpe				1	0	1
Hydraulikk Tank			2	1	2	1
Hydraulikk Vacuum			1	1	1	1
Hydraulikkanlegg			15	1	15	1



Fremdriftspumpe

Finner de registerte feilene fra regneark TV1, bruker rapport nr her fra i regneark 'Kostnader ordre' til å finne kostand per ordre, bruker ordre nr her fra til å finne materiell kost i regneark 'Materiell kostander'

Feildata TV1					
Teknisk plass	**Betegnelse**	**Kodetekst**	**Rapportdato**	**Rapport**	**Beskrivelse**
80051426	HYDRAULIKKANLEGG TAPP	Hydraulikk Fremdriftspumpe	16.08.2017	22428678	REK. DA-ventil
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	13.05.2015	21693886	Justere DA-ventil
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	02.08.2013	21249149	Justere fart
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	07.10.2014	21523047	TAPPEVOGN NR01 HYDEQ Rep. SF - Kontroll
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	31.07.2013	21248493	TV 1 oljelekk bak i motorrom...
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	31.07.2013	21248493	TV 1 oljelekk bak i motorrom...
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	31.07.2013	21248493	TV 1 oljelekk bak i motorrom...
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	08.11.2013	21292786	Ulyd i hydraulikk, + lekkasje hydraulikk
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	18.08.2011	21105538	Vogna stod i gir framover, men gikk bako
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Fremdriftspumpe	18.08.2011	21105538	Vogna stod i gir framover, men gikk bako

Feildata TV1			Kostander ordre		Kostnader materiell		
Skadekode	**Aktivitetskode**	**Kodetekst akt.**	**Ordre**	**Tot.kostn. fakt**	**Budsj./transVal**	**Verdi/trans.valuta**	**Bud./rapp.val.**
0014	0024	Fikset	104211339	1 791,00			
0003	0019	Skiftet	102974479	7 759,00			
0005	0007	Fikset	102192235	88 924,87	21 086,00	0,00	21 086,00
0014	0007	Fikset	102660531	438 622,07	16 716,83	0,00	16 716,83
0012	0019	Skiftet	102191551	83 028,23			
0012	0019	Skiftet					
0012	0019	Skiftet					
0012	0017	Fikset	102261129	24 000,00	3 114,80	1 557,40	3 114,80
	0019	Skiftet	101889708	99 052,18			
	0019	Skiftet					

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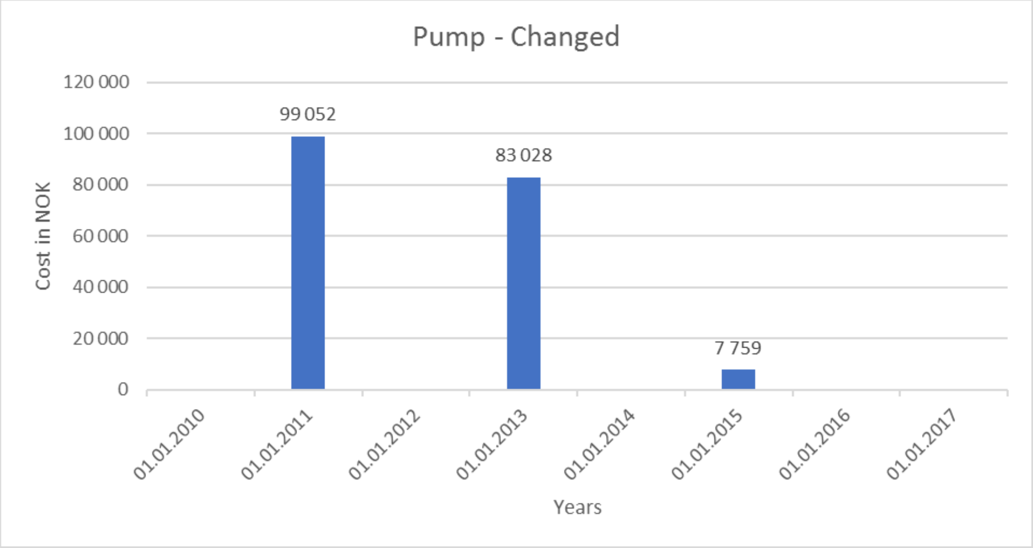
31.07.2013	83 028,23
18.08.2011	99 052,18



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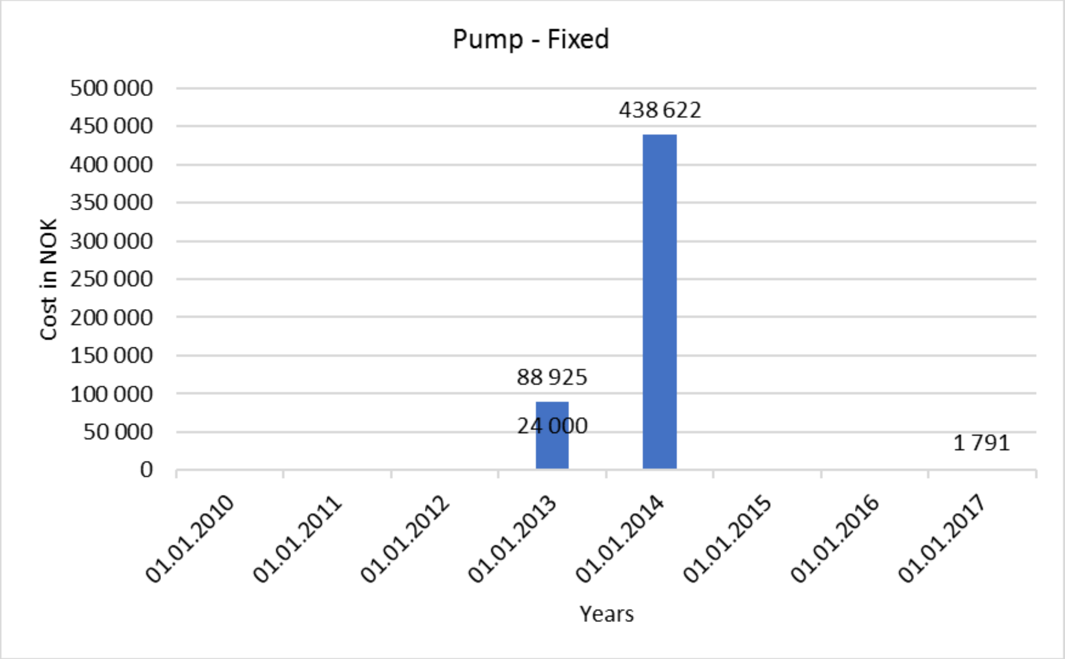
07.10.2014	438 622,07
08.11.2013	24 000,00



		Pump
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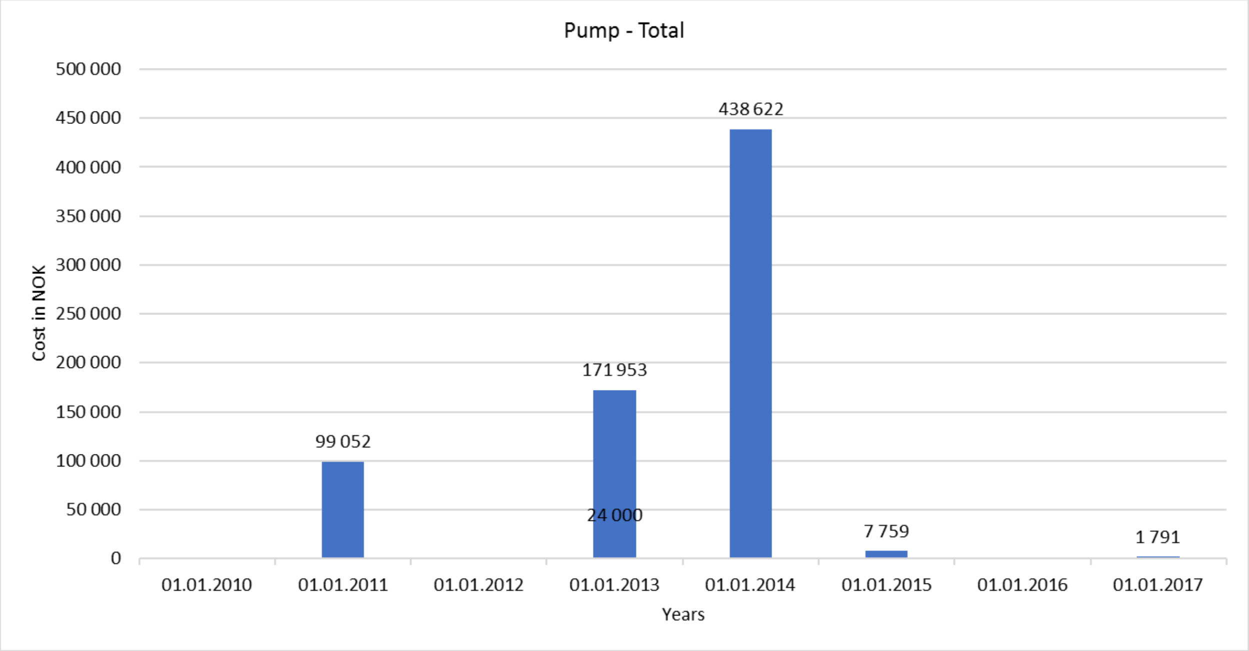
	13.05.2015	7 759,00
	07.10.2014	438 622,07
	08.11.2013	24 000,00
Legger sammen 31.07 og 02.08 til 01.08	01.08.2013	171 953,10
	18.08.2011	99052,18



Hydraulikk motor

Finner de registerte feilene fra regneark TV1, bruker rapport nr her fra i regneark 'Kostnader ordre' til å finne kostand per ordre, bruker ordre nr her fra til å finne materiell

Feildata TV1					
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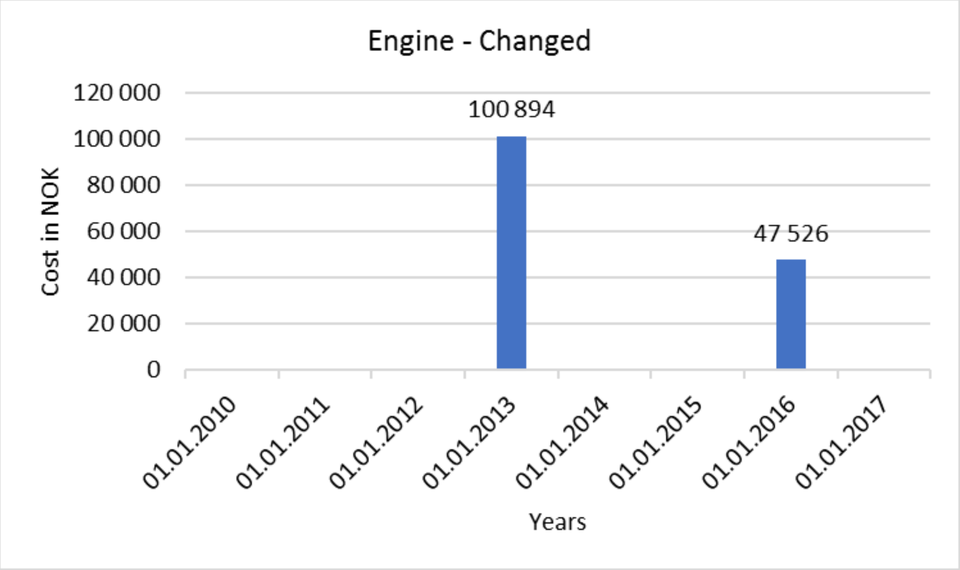
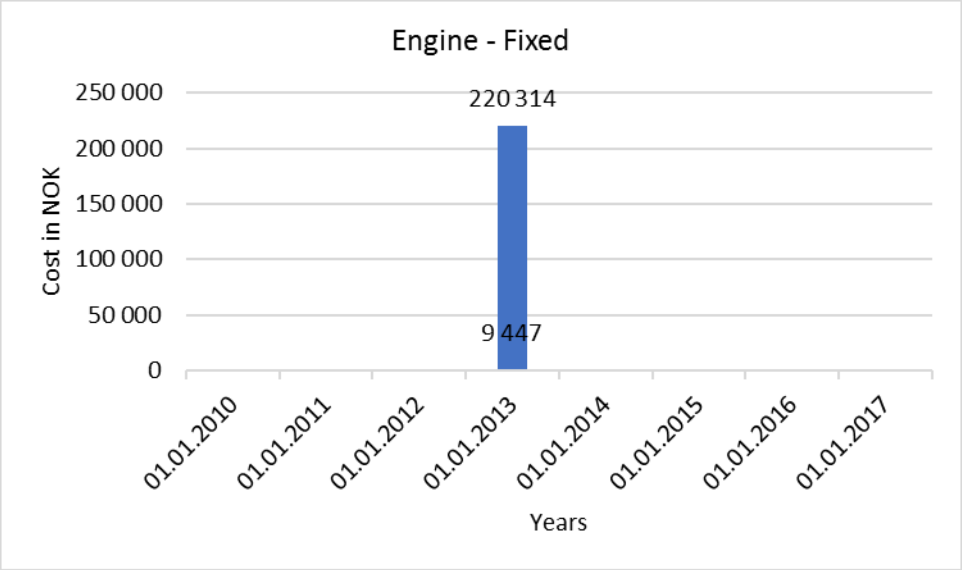
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Motorer	10.12.2013	21306427	Avtapping av olje fra gir
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Motorer	10.12.2013	21306427	Avtapping av olje fra gir
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Motorer	23.04.2013	21228101	Rep. etter SF kontroll
80051419	TAPPEVOGN NR01 HYDEQ	Hydraulikk Motorer	06.12.2013	21304792	Stor Hydr.Lekk=>Røket fremdr.slange?
80051426	HYDRAULIKKANLEGG TAPPE	Hydraulikk Motorer	11.12.2016	22202304	Prebake tapping TV1 hyd.pumpe-havari
80051426	HYDRAULIKKANLEGG TAPPE	Hydraulikk Motorer	11.12.2016	22202304	Prebake tapping TV1 hyd.pumpe-havari

Feildata TV1			Kostander ordre		Kostnader materiell		
Skadekode	**Aktivitetskode**	**Kodetekst akt.**	**Ordre**	**Tot.kostn. fakt**	**Budsj./transVal**	**Verdi/trans.valuta**	**Bud./rapp.val.**
0012	0019	Skiftet	102280389	100 894,49			
0012	0019	Skiftet					
0012	0019	Skiftet					
0012	0018	Fikset	102147672	220 314,24	5 617,00	0,00	5 617,00
0012	0003	Fikset	102277781	9 447,00	3 447,01	0,00	3 447,01
0006	0019	Skiftet	103827814	47 526,00			
0006	0019	Skiftet					

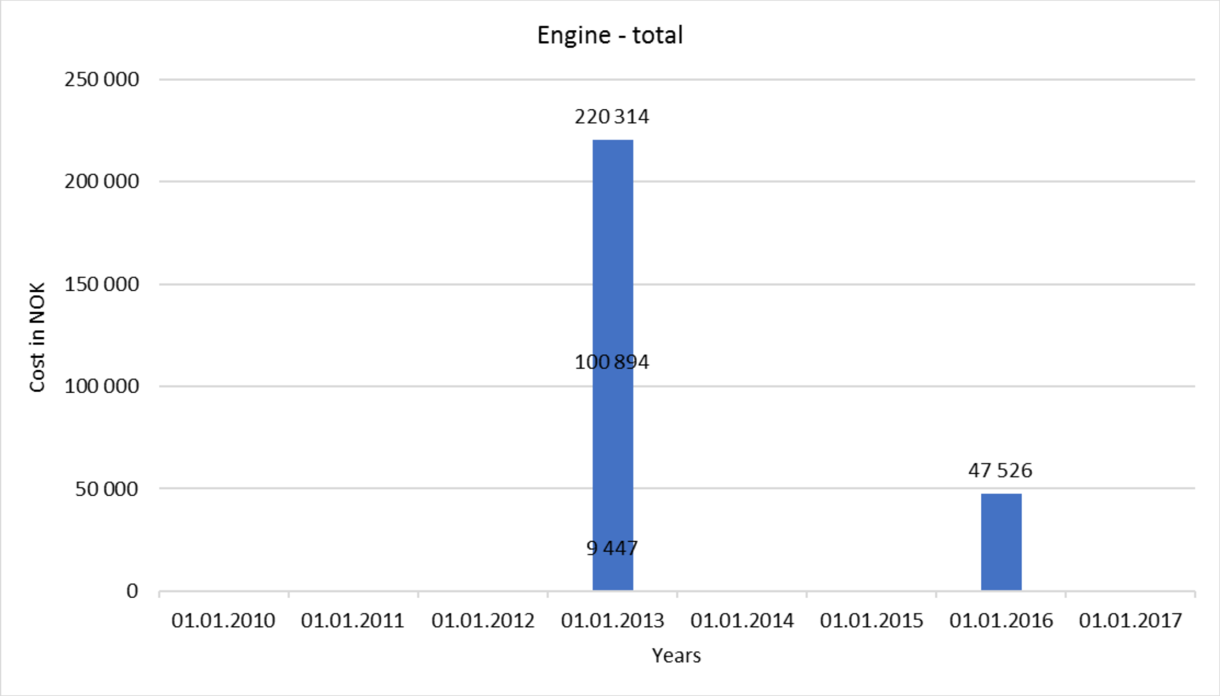
	Changed
	Engine
10.12.2013	100 894,49
11.12.2016	47 526,00



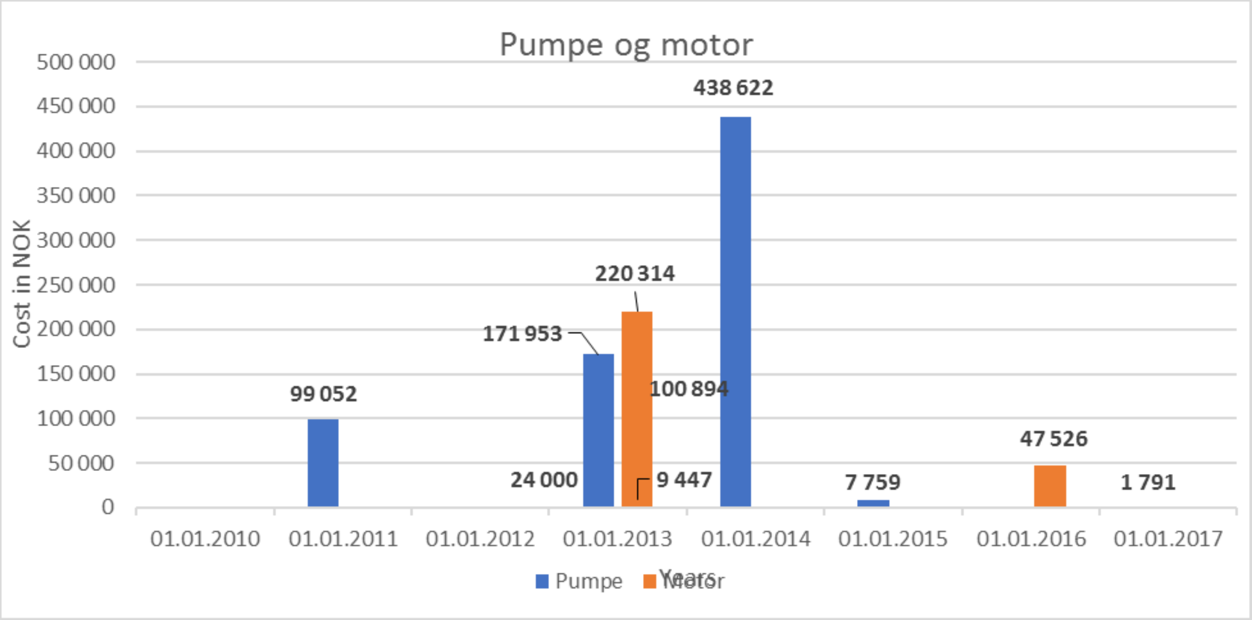
	Fixed
	Engine
23.04.2013	220 314,24
06.12.2013	9 447,00



	Pump total
23.04.2013	220 314,24
06.12.2013	9 447,00
10.12.2013	100 894,49
11.12.2016	47 526,00



	Cost	Pumpe	Motor	Hose
	18.08.2011	99 052		
02.08.2013	01.08.2013	171 953		
31.07.2013				
	08.11.2013	24 000		
	07.10.2014	438 622		
	13.05.2015	7 759		
	16.08.2017	1 791		
	23.04.2013		220 314	
	06.12.2013		9 447	
	10.12.2013		100 894	
	11.12.2016		47 526	
			Aprox. Cost	
	New tapping carriage		kr 5 700 000,00	
	New hydraulic system		kr 1 000 000,00	



Appendix B:

KMV

Forebyggende Vedlikeholdsplan

M = Måling
I = inspeksjon (visuell)
K = kontroll
F = Funksjonstest
R = Rengjøring
U = Utskifting
J = Justering
S = Smøring

Benevnelse Teknisk		**Ordre nr.**	
Tekn. plass nr.		**Utførende Fag**	
Revisjon nr.	**3**	**Utført dato:**	
Rev.dato	**11.04.2017**	**Utført sign.**	
Revidert av.	**Tor Magne Rydland**		

HMS hensyn	**Verktøyliste**	**Antall**	**Plassert**

Tag / ID	Objektdel	Vedl. Beskrivelse	Type VH	EPL / SOP	Materiell	Aksept grense	300t	600t	1200t	2400t	4800t	26U	52U	104U	Utført	Feil funnet / reg.verdi
Annen utrystning	0889	Mastruller, tilstand.	SF										I			
Annen utrystning	0835	Kontroll av luft sylindere/tilstand	SF										K			
Annen utrystning		Kontroll hastighet , samkjøring og endedemping luftsylindre	SF									F	F			
Annen utrystning	0845	Kontroller regulator/tørkefilter (trykk,urenheter)	SF		232877							K	K			
Annen utrystning		Kontroll drenering luft tanker	SF									K	K			
Chassis og førerhus	0160	Kontroll måling vanger etter mal.	SF										M			
Chassis og førerhus	0162	Kontroll oppheng for diglelokk	SF									K	K			
Chassis og førerhus	0161	Rengjøre traverseringsruller	SF										R			
Chassis og førerhus	0161	Måle slitasje/slakk på traversringsruller	SF										M			
Chassis og førerhus	0154	Hengsler/sikringer (førerhus,motor og vakumpumpedeksel)	SF									S	S			
Chassis og førerhus		Sprekker/skader/defekter.	SF									I	I			
Chassis og førerhus	0165	Kontroll førestol m/sikkerhetsbelte	SF										K			
Chassis og førerhus	0150	Kontroll av Varselskilt	SF										K			
Chassis og førerhus	0130	Kontroll speiler (matr nr 217820)	SF									K	K			
Chassis og førerhus	0105	Rengjøring av vogn	SF									R	R			
EL Anlegg	0205	Dynamo / lading /hvilespenning	SF										M			
EL Anlegg	0225	Kontroll Kabler	SF										I			
EL Anlegg	0210	Kontroll Hovedbryter	SF										I			
EL Anlegg	0221	Kontroll Natostøpsel	SF										I			
EL Anlegg	0259	Kontroll nødstoppbryter	SF										I			
EL Anlegg	0220	Kontroll Instrumenter	SF									F	F			
EL Anlegg	0235	Funksjonstest Lys	SF										F			
EL Anlegg	0250	Varselordringer. (eks høy last,lydalarmer)	SF									F	F			
EL Anlegg	0240	Kontroll parameter MC 7	SF										K			
EL Anlegg		Kontroll hastighet lav ca 10 km/t høy ca 20 km/t flat vei	SF										K			
EL Anlegg	0255	Skifte endebrytere støttelabber (4 stk	SF U		239044								U			
EL Anlegg	0265	Skifte dynamo	SF U		270024								U			
EL Anlegg	0205	Skifte Startmotor	SF U		217923								U			
Hydraulikkanlegg	0635	Kontroll tilstand slanger	SF									K	K			
Hydraulikkanlegg	0680	Kontroll tilstand rør	SF										K			
Hydraulikkanlegg	0681	Kontroll tilstand kuplinger	SF										K			
Hydraulikkanlegg		Kontroll nødkjøring arbeidhydr.	SF									K	K			
Hydraulikkanlegg		Utfør test av slepeprosedyre	SF									F	F			
Hydraulikkanlegg		Måle LS trykk Arb. Hydr. 23-28 bar	SF										M			
Hydraulikkanlegg	0641	Kontroll DA ventil (fremdriftspumpe) 1050 omdr. ved igangsetting.	SF										K			
Hydraulikkanlegg		Funksjonstest av sylindere for løft og traversering.Hastighet ned og ut ca.20sek.	SF										F			
Hydraulikkanlegg		Høytrykk lokk (220bar)	SF			220 bar							K			
Hydraulikkanlegg		Kontroll fjæringsfunksjoner	SF										K			
Hydraulikkanlegg		Kontroll/etterfylling av Akkumulator brems	SF										K			
Hydraulikkanlegg	0683	Kontroll/etterfylling akkumulatorer Fjæring	SF										K			
Hydraulikkanlegg	0684	Kontroll/etterfylling akkumulatorer digellokk	SF										K			
Hydraulikkanlegg	**0636**	**Skifte korte fremdriftsslanger**	**SF U**										**U**			
Hydraulikkanlegg	**0635**	**Skifte Slanger fremdriftspumpe**	**SF U**										**U**			
Hydraulikkanlegg	**0637**	**Skifte lange fremdriftsslanger**	**SF U**											**U**		
Kraftoverføring og bremser		Fotbrems og parkbrems funksjon	SF										F			
Kraftoverføring og bremser	0400	Aksial/radialstag og foringer	SF										K			
Kraftoverføring og bremser	0405	Inspeksjon Dekk. Se at dekk ikke har skader, skjevslitt, eller utslitt.	SF									I	I			
Kraftoverføring og bremser	0406	Inspeksjon Felg. Se etter skader/avvik på felg.	SF									I	I			
Kraftoverføring og bremser	0407	Sjekk at hjulbolter sitter fast. Skal settes med moment	SF			550Nm						K	K			
Motor	0307	Kompressor kontroll tilstand.	SF		231592								K			
Motor	0300	Kontroll kjølerør / slange ut fra kompressor	SF									K	K			
Motor		Kontroll lekkasjer samt defekter.	SF									I	I			
Motor		Effekt kontroll motor (kaibakken min.1800 omd. U/last).	SF										I			
Motor		Kontroll motorturtall (Tomgang 750 omdr.Maks 2130 -2160 omdr.) NB kontroll kule ledd og arm.	SF										K			
Motor		Lese av og registrere timestand	SF									M	M			
Motor	0313	Ventiljustering (E 0,45, I 0,20)	SF										J			
Smøreanlegg		Se DMS dokument 500324646	SF										X			
Spesialutrystning	0741	Rengjøre innløp for vakuummeter filter	SF									R	R			
Spesialutrystning	0830	Kontroll av luftslanger for sylindere digellokk	SF										K			
Spesialutrystning	0775	Kontroll av feste for stativ/veieceller.	SF										K			
Spesialutrystning	0753	Kontroll oppheng viagrarør	SF										K			
Spesialutrystning	0754	Kontroll oppheng tapperør	SF										K			
Spesialutrystning	0722	Kontroll av støttelabber	SF									K	K			
Spesialutrystning	0722	Smøre støttelabber	SF									K	K			
Spesialutrystning	0722	Rengjøre støttelabber	SF									K	K			
Spesialutrystning	0723	Kontroll av endebrytere støttelabber samt rengjøres og smøres	SF									K	K			
Spesialutrystning		Kontroll slanger og rør vakuum system	SF										K			
Spesialutrystning		Kontroll PLS for blåsing Cooper King 45sek. Pausetid x 8. Filterkontroll	SF										K			
Spesialutrystning		Kontroll av Vakuum og trykk 0,6 - 0,7bar.Kjølevifte for vakuum	SF										K			
Spesialutrystning	0742	Innsugfilter i vakuumpumpe kontroll og rengjøres / skiftes	SF U										U			
Spesialutrystning	0742	Innsugfilter i vakuumpumpe kontroll	SF									K	K			
Spesialutrystning	0744	Kontroll av seperasjonsfilter vakuumpumpe. (røykutvikling ved drift)	SF										K			
Spesialutrystning		Linjefilter AF4753 MP (matr nr 231553) og innerfilter AF4761M skiftes Cooper King skiftes	SF U		231553								U			
Spesialutrystning	0775	Kalibrering Veieceller sammen Elektroavdeling	SF									K	K			
Styresystem	0500	Endestopp styrestag / hjulsving	SF									K	K			
Styresystem	0530	Styresylindere m / styrestag	SF									I	I			
Styresystem	0540	Kontroll hjuloppheng (kingbolt lager)	SF										K			
Styresystem	0541	Innfestning drivaksel framme og bak	SF										I			
Styresystem	541	Hjulstilling / midtstilling /Rengjøring sensor bakhjul	SF									K	K			

Appendix C:

Intervju med Tor Magne Rydland
Stilling: Vedlikeholds avdelingen, fagleder mobilt utstyr.

05.04.18

1. **Hvordan forgår vedlikehold av kjøretøy på Hydro? Preventive/Corrective?**
   Begge deler, men mest korrigerende. Alle kjøretøyer har planlagte kontroller/Servicer, men det varierer hvilke og hvor mange ut ifra hvilke kjøretøy det er snakk om.
   Tappe vognene er litt spesielle på det området for det er satt i gang spesielt mange tiltak på disse.

   Korrigerende vedlikehold når noe "u-planlagt" skjer. Hvordan vedlikeholds operasjonen blir videreført kommer mye an på kritikaliteten.

2. **Kan du fortelle litt om Preventive mainetance på Hydro?**
   Det er ikke alt utstyr som har forebyggende vedlikehold. For noen år tilbake ble det lagt ned mye arbeid i å lage en plan for forebyggende vedlikehold på tappevognene, fordi det va mye problemer med disse så disse ble prioritert. Har kommet et godt stykke, men mye gjenstår. Skulle hatt forebyggende vedlikehold på mer utstyr.

   Fremdriftsslangene er en av komponentene som blir påvirket av det forebyggende vedlikeholdet. De blir nå skiftet ut på de servicene/SF'ene.

3. **Hvordan foregår vedlikehold av Tappe vognene i forhold til andre kjøretøy? Er nedetid kritisk?**
   Mye mer systematisk vedlikehold på tappe vognene enn for eksempel ATV.
   SF 2 ganger i året, etter 26 og 52 uker. 52 uker er den største, alt det samme som 26 uker men også mye mer.
   Service etter 300 timer i drift. Drift ca 3500 timer i året. -- > 3500/300 =11,7 --> Service ca 1 gang i mnd.
   For øyeblikket er det 8 tappevogner, og hvis alt går som det skal når piloten starter opp bør det være nok med 4 som alltid er i drift. Nedetid på vognene er ikke direkte kritisk, men kan fort bli om flere "streiker" samtidig. Takler at 1- 2 er nede eller til rep/service, 3 kan gå til nøds, 4 er krise.

4. **Hva er jobben din/vedlikeholdsavdelingen?**
   Sørge for av vedlikehold går som det skal, både korrigerende og forebyggende, gjennomføre vedlikeholdanalyser av utstyr og drive med oppfølging og utvikling av vedlikehold på KMV sitt mobile utstyr.

5. **Er det Bilfinger som utfører både forebyggende og korrigerende vedlikehold?**
   Ja. Det forebyggende vedlikeholdet er planlagt og skal utføres til faste tider. Korrigerende vedlikehold må tas som det kommer, og blir vurdert ut ifra kritikalitetsnivået.

6. **Hvem bestemmer hva som må gjøres for å fikse kjøretøyene? Repair/Replace?**
   Det er et fast opplegg å følge for service og SF, mens korrektivt vedlikehold utføres etter hvert. Dersom det er noe som ikke haster, blir reparasjon ofte utsatt til neste service eller

SF dersom den uansett nærmer seg.
Er det "små" ting så håndterer mekanikerne fra Bilfinger dette, hva som må fikses, skiftes osv. Dersom operasjonene blir litt større diskuteres det mellom mekanikerne og vedlikeholdsavdelingen. Det er et godt samarbeid mellom enhetene, det hele pleier å starte med en telefonsamtale om hva som er problemet også tar vi det der fra. Er det noe som haster må kanskje Bilfinger ut i driften og hente kjøretøyet/utstyret og fikse det så fort det lar seg gjøre, mens andre ganger når det er mindre kritisk blir det først lagt inn en bestilling i SAP på hva som er problemet osv.

7. **Hva baseres beslutningene på? Tilstand eller kostnad?**
   Beslutningene om hva som må gjøres baseres mye på hvor kritisk feilen er, hvor lang tid en eventuell ny del vil ta for å bli levert i forhold til å reparere, dersom det er generasjon skifte på utstyr vil dette bli tatt med i betraktningen, og selvfølgelig pris. Men i hovedsak er det fokus på at vognene ikke skal være for lenge ute av drift, da dette i verste fall kan påvirke produksjonen (aluminiumsproduksjonen). Der det er innført forebyggende vedlikehold er det allerede tatt en beslutning basert på tidligere tilstander, og sa byttes disse komponentene når det er planlagt uansett tilstand og kost.

8. **Det er mye utskifting av fremdriftsslangene, hvorfor? Blir den bare byttet, eller reparert også?**
   Bare byttet.
   Grunnen til at fremdriftsslangene byttes så ofte er at det ble laget en forebyggende vedlikeholdsplan basert på store vedlikehold operasjoner da disse slangene røk/ble ødelagt av seg selv mens vognen var i drift. Det tok mye tid å fikse, var mye gris og var absolutt en situasjon som ville unngås. Den forebyggende vedlikeholdsplanen ble derfor opprettet, og etterpå har ikke dette vært et problem. Derimot kan der være at slangene skiftes for hyppig, at de kanskje hadde holdt litt lenger og dermed også kuttet kostnad.

9. **Hvor ofte må de byttes?** Det et totalt 8 fremdriftsslanger og 6 av disse skiftes ut kontinuerlig, forebyggende vedlikehold. 4 av dem skiftes hvert år, mens 2(de lange) skiftes annen hvert år, fordi disse ligger mer gjemt og er ikke utsatt for samme slitasje som de 4 andre. De 2 siste er ikke under denne preventive vedlikeholdsplanen.