CHALMERS
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Evaluation of the Potential for Predictive Maintenance

A Case Study at Fortum

Master's thesis in Production Engineering and Sustainable Energy Systems

BJÖRN KANGE
STEFAN LUNDELL

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

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Master of Science Thesis [Production Engineering, MPPEN; Sustainable Energy Systems, MPSES]
BJÖRN KANGE
STEFAN LUNDELL

Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

ABSTRACT

This report regards a master's thesis conducted at Fortum in cooperation with Chalmers University of Technology. The purpose of this thesis was to investigate the prerequisites for a Predictive Maintenance (PdM) program within the power industry and to evaluate the potential for PdM practices at Fortum. The results from this thesis identified that both strengths and barriers to a PdM implementation exist within Fortum. The nuclear power plant Loviisa stood out in both the situation analysis and the benchmarking analysis, and thus was identified as a front-runner within the company regarding both utilization of production measurements, and organizational structure, within the maintenance organization. It was concluded that Fortum generally showed high potential of moving towards PdM on an operational and technological level. The main obstacle was instead found at an organizational level, as standard processes for how to utilize production measurements were found to be missing. PdM is a development of Condition Based Maintenance with focus not only on the current condition of the equipment but also evaluates historical data to reveal trends and detect beginning deterioration at an early stage. Fortum is a producer and supplier of heat and power and thus shares the issues of the power industry, for instance maintaining high dependability and avoiding costly downtime. As a means to counteract these threats, PdM has been of interest for Fortum. Therefore, the aim of this thesis was to evaluate the potential of PdM by investigating requirements and barriers to a successful implementation of a PdM program at Fortum. The research was conducted as a case study, including a literature review, a situation analysis, benchmark analysis and an archival review. Data for the situation analysis was collected via questionnaires and interviews. The benchmarking was performed at the Loviisa nuclear power plant, Krångede hydro power plant and Heat South Sweden (the southern heat and power production area of Sweden). For this, SKF's Client Needs Analysis was utilized. Moreover, a review of relevant academic literature as well as an archival review of internal documents was performed.

Keywords: Case study, Predictive maintenance, Condition based maintenance, Implementation, Maintenance development

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Björn Kange and Stefan Lundell

TERMINOLOGY

The following list presents a set of abbreviations that are frequently used in this thesis.

PdM - Predictive Maintenance

CBM - Condition Based Maintenance

PM - Predetermined Maintenance

RCM - Reliability Centered Maintenance

CNA - Client Needs Analysis

FMEA - Failure Mode and Effect Analysis

RCFA - Root Cause Failure Analysis

KPI - Key Performance Indicator

EAM - Enterprise Asset Management (System)

SCADA - Supervisory Control and Data Acquisition (System)

PI - Process Information (System)

PDS - Predictive Diagnostic Software

O&M - Operations and Maintenance

CHP - Combined Heat and Power

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1. Introduction

This section introduces the reader to this thesis and includes a brief background to the subject area and presents the purpose and goals of this project. Furthermore, the research questions are stated and explained. Lastly, the delimitations are listed in order to further define the scope of this thesis.

1.1. Background

The significance of maintenance operations within the process industries has evolved over the last century form a being viewed as a ”necessary evil” to becoming an important tool for sustaining a viable production environment. Nowadays, world-class companies have acknowledged the fact that maintenance operations are strongly influencing the business profitability since it has a direct impact on production cost, quality, reliability and the level of tied up capital. Thus, by practicing an efficient maintenance program, both profitability and productivity can increase (Maletic et al. 2014).

Avoiding downtime is a key factor for business profitability within the power industry. Since the ability to store energy is low, it is highly important to be able to produce the right amount of power at the right time. Due to the low buffers, an unplanned stoppage is extremely costly when demand is high; hence the plants need to be dependable. Furthermore, the cost of maintenance can vary widely between different forms of power and heat production facilities but is of great importance to any energy producing business (International Coil Organization 2015).

With the current development of Industry 4.0, production data is becoming an increasingly important asset for maintenance operations. By continuously collecting and analyzing production data, costly corrective maintenance work can be reduced since surprising equipment malfunction is avoided (Carnero 2006). Accurate production data is the foundation to Predictive Maintenance (PdM), which is a maintenance approach that focuses not only on the current condition of the equipment but also evaluates historical data to reveal trends and detect beginning deterioration at an early stage. For instance, physical parameters (e.g. vibration and temperature) are measured and compared to the expected values. This provides knowledge not only about the current, but also the expected future equipment condition. The resulting output of a PdM program can be used to optimize maintenance and operations and thus reduce the cost for maintenance and increase profit by avoiding unplanned downtime. Unnecessary preventive actions are also reduced since the actual need for repair can be controlled closely (Prajapati, Bechtel & Ganesan 2012).

Fortum is a producer and supplier of heat and power and thus shares the issues of the power industry, for instance maintaining high dependability and avoiding costly downtime. As a means to counteract these threats, PdM is of interest for Fortum. Therefore, the aim of this thesis is to evaluate the potential of PdM by investigating requirements and barriers to a successful implementation of a PdM program at Fortum.

1.2. Purpose

The purpose of this thesis is to evaluate the potential for predictive maintenance at Fortum, by identifying possible barriers and requirements to a successful PdM implementation.

1.3. Objective

In order to specify the aim of this study the following research questions is stated and addressed throughout the course of this thesis:

RQ1. What are the possible barriers to a successful implementation of PdM at Fortum?

RQ2. To what degree are the maintenance practices at Fortum aligned with PdM practices?

The first research question will be investigated through a literature review along with archival research of previous PdM related actions at Fortum. The aim for this question is to identify a set of key barriers, which are of importance to avoid in order to enable a successful PdM implementation.

The second research question is to be studied through a situation analysis, to elucidate the current maintenance practices at Fortum. In addition, a benchmark will be conducted in order to obtain a wider picture of the current status of the maintenance performance at each of the concerned facilities. The output of the situation analysis will be compared with PdM practices, identified through the literature review. Together with important findings from the archival research, the current alignment with PdM can be investigated.

These questions will serve as a basis for the evaluation of PdM practices at Fortum.

1.4. Scope

The thesis includes an investigation of the existing maintenance approaches at Fortum's production facilities with focus on data handling and management of production measurements. A benchmark focused on the maintenance organization of three separate production units is also included. Based on the situation analysis, the benchmark and the key findings from the archival review, the potential for a PdM implementation within Fortum is assessed. This report serves as background to a future feasibility study on the implementation of PdM within Fortum.

1.5. Delimitations

This project does not regard technically detailed analyzes on an operational level of Fortum's processes. Instead, a more holistic perspective is taken, with the general maintenance procedures of Fortum's facilities as point of interest. Furthermore, the distribution systems, the solar plants in India and the thermal plants (which are only operated during peak conditions) are not included in this study. Also, the Russian branch of Fortum is not a part of the study.

2. Theoretical framework

In this section a background to the company in focus in this project, Fortum, is presented followed by an explanation of key maintenance concepts related to this study. Important research on the topic of PdM is also presented and the reader is provided with a background to the use of predictive methods within the power industry.

2.1. Case background

Fortum is a heat and power producing company with operations focused on the Nordic countries, Russia, Poland and the Baltics. The production fleet includes hydro, nuclear, combined heat and power (CHP) and condensing power plants. Fortum is divided into following operational divisions: (Fortum 2015)

HES: includes the combined heat-and-power plants (referred to as *Heat* in this study)

HPT: includes the hydropower facilities (referred to as *Hydro* in this study)

NPT: includes the nuclear plant and condensing power plants (referred to as *Nuclear* in this study)

In general, the maintenance responsibility is divided between teams within each division; the thermal, nuclear and CHP-plants generally have dedicated maintenance teams while the responsibility for hydropower maintenance and operations is divided between the three areas; Hydro South Sweden, Hydro North Sweden and Hydro Finland. The overall maintenance operations are coordinated by the Operations and Maintenance board (O&M), but the actual maintenance planning and practices differs somewhat with location and division (Fortum 2015). Figure 1 shows the geographical location of the production units that are considered in this study. This includes 16 CHP-plants located in Sweden, Finland, Estonia, Latvia, Lithuania and Poland, the condensing plant in Meri-Pori and the Loviisa nuclear plant. Fortum's 127 hydropower facilities in Sweden and 33 facilities in Finland are also included but not marked on the map. The further division of the Swedish production units within Heat and Hydro is listed below (Fortum 2015).

Heat Sweden

- Heat South Sweden
  - Högdalen
  - Hammarby
- Heat North West Sweden
  - Brista
  - Hässelby
- Heat City Sweden
  - Ropsten
  - Värtan

Hydro Sweden

- Hydro North Sweden
  - Ångermanälven
  - Indalsälven
  - Ljungan
  - Ljusnan
- Hydro South Sweden
  - Dalälven
  - Klarälven
  - Byälven
  - Norsälven
  - Gullspångsälven

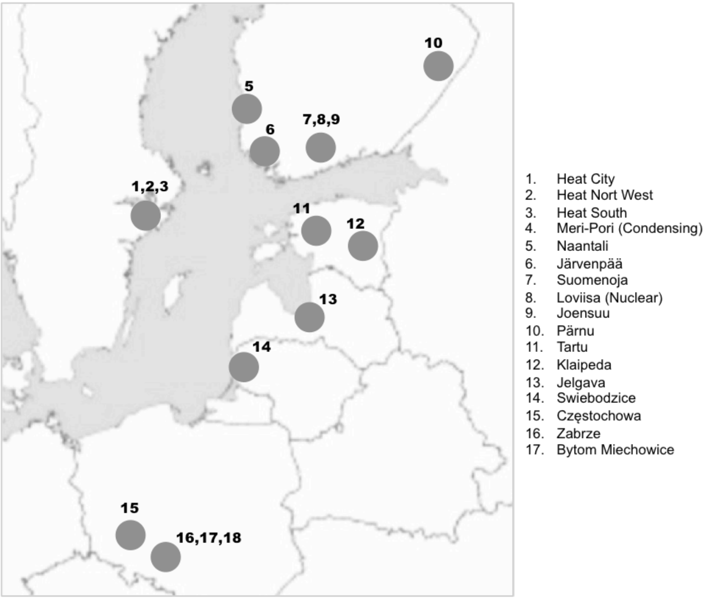

Figure 1: The units within Heat and Nuclear that are included in the scope of this thesis.

In order to give the reader a further introduction, some general technical data concerning Fortum's production units are presented below. **Table** 1 shows the capacity and estimated production data for each of the CHP, nuclear and condensing units, based on the information presented at Fortum's website (Fortum 2015).

Table 1: The capacity and approximate heat and power generation for the plants within Nuclear and Heat that are included in the study.

Plant	Commission year	Power Capacity [MW]	Heat Capacity [MW]	Approx. power prod. [GWh/year]	Approx. heat prod. [GWh/year]	Fuel type
Brista	1997	54	126	400	1300	Biomass and waste derived fuels
Hässelby	1959	75	194	200	800	Biomass
Högdalen	1970	66	358	200	2200	Waste derived fuels
Värtan	1977	410	2100	500	2600	Coal and biomass
Meri-Pori	1994	565	0	N.A	0	Coal
Naantali	1960			1000	1500	-
Suomenoja	1977	565	370	N.A	N.A	Coal and natural gas
Joensuu	1986	50	218	N.A	N.A	Wood and peat
Loviisa	1977	992	0	8000	0	Uranium
Järvenpää	2013	22	60			Biomass

Pärnu	2010	24	50	110	220	Biomass
Tartu	2009	25	50	170	340	Biomass and peat
Klaipeda	2013	20	50	140	400	Biomass and waste-derived fuels
Jelgava	2013	23	45	110	230	Biomass
Swiebodzice		5	16	N.A	N.A	Natural gas
Cz□stochowa	2010	60	120	N.A	N.A	Coal and biomass
Zabrze	1897	74	475	150	500	Coal and biomass
Bytom	1954	55	372	N.A	N.A	Coal

Furthermore, Figure 2 shows the power generation capacity for each division and country, while Figure 3 shows the heat production capacity for each country. Note that Russia is not included in this presentation.

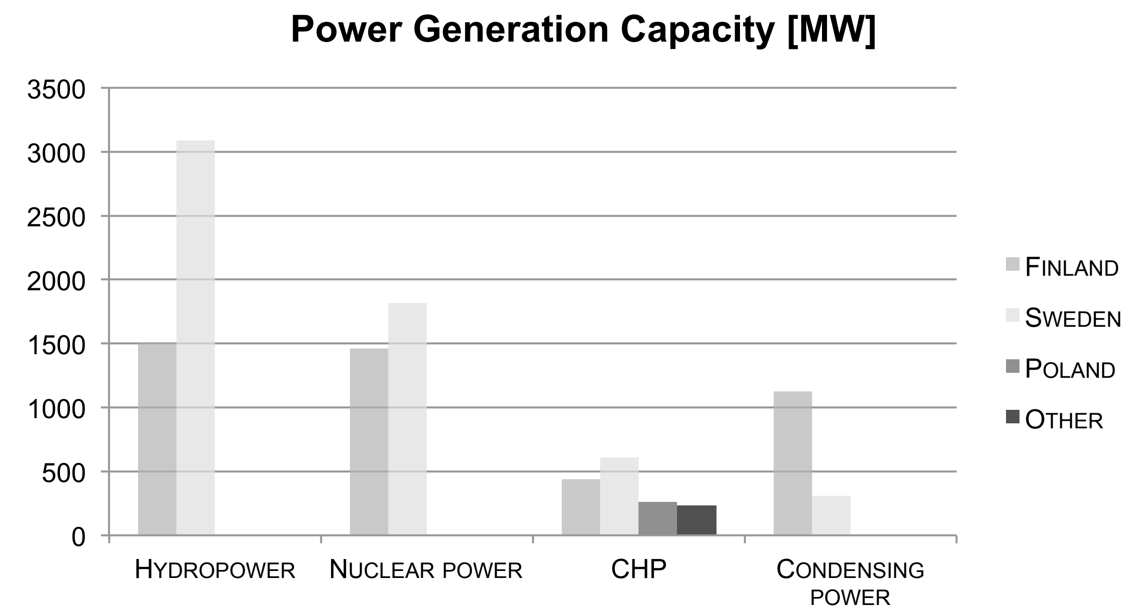

Figure 2: The total power generation capacity of Fortum (apart from the Russian division) divided between countries and division.

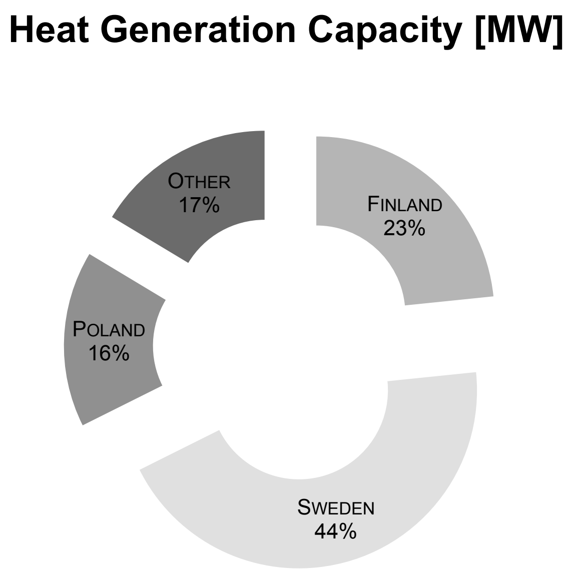

Figure 3: The total heat generation capacity shown for each country (Russia not included).

2.2. Fundamental maintenance theory

The scope of this project involves research of different maintenance approaches and concepts, fundamental theory used in this report is defined below. In compliance with Fortum the maintenance terminology used is in accordance with standard provided by the Swedish Standard Institute (2001).

2.2.1. Maintenance

The definition of maintenance according to Swedish Standard Institute (2001) is; "the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (Swedish Standard Institute 2001).

2.2.1. Dependability

As the definition of maintenance reveals, the purpose of maintenance is to keep an item operational at required level. One way of expressing to what degree this is achieved is by quantifying its dependability. Dependability can however be defined in many different ways, for instance by the cost or time-consumption of maintenance (Fowler 2005). According to Swedish Standard Institute (2001) dependability is a "collective term used to describe the availability and its influencing factors: reliability, maintainability and maintenance supportability."

2.2.2. Reliability

Reliability is "the ability of an item to perform a required function under given conditions for a given time interval" (Swedish Standard Institute 2001). According to Fowler (2005) reliability is a quantitative measurement for the probability of a system being operational during a specific period of time. Hence, how long a system can run correctly without any kind of interruption.

2.2.3. Availability

Availability is defined as: "the ability to be in a state to perform as and when required, under given conditions, assuming that the necessary external resources are provided" (Swedish Standard Institute 2001). Fowler (2005) describes availability as the probability that a system is operational at a specific time. As opposed to reliability, it does not only take eventual interruptions into consideration but the ability to become operational again as well, defined as maintainability. Therefore, a system can be considered to have high availability even though it experiences sporadic interruptions (Fowler 2005). According to Almström & Kinnander (2011) availability is defined as the ratio of planned production time minus breakdowns and changeovers over planned production time.

2.3. Maintenance types

In this study, a maintenance type is defined by what causes initiation of maintenance actions. In Figure 4, the interrelation of the maintenance types concerned in this report is illustrated. Maintenance is divided into Preventive and Corrective maintenance. The Preventive Maintenance approach is further divided into Condition Based Maintenance (CBM) and Predetermined Maintenance (PM). In the following sections, a brief historical background to the development of these maintenance types is presented and the definition of each type is given.

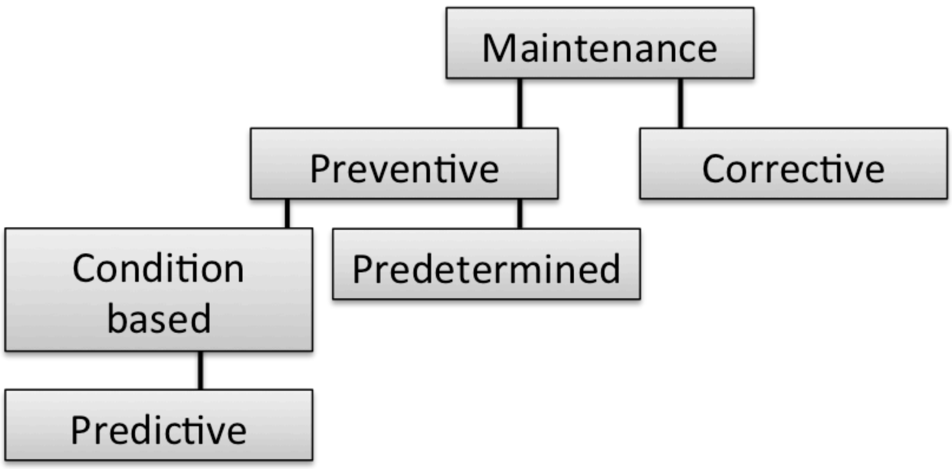

Figure 4: The interrelation of the maintenance types concerned in this study.

2.3.1. Historical development of the maintenance types

Throughout the course of the last century, the approach to maintenance of industrial production and process systems has seen major development. During the first half of the 20th century the industrial equipment was simple and in general over-dimensioned – the effect of equipment malfunction was not critical to operations and often ignored. Industrial machinery was operated until failure and maintenance was only performed after fault recognition (Alsyouf 2006). The cause of failure was normally not considered and maintenance activities focused on restoring and repairing the asset to fully operational conditions. This type of reactive approach is commonly referred to as "run-to-failure" or corrective maintenance.

Along with the end of the Second World War an increase in product demand and a booming market in the west pushed the development of the industrial production systems. The industrial equipment became more complex and along with a higher focus on production costs, the role of maintenance became increasingly important. The "fix when it breaks"-mentality, which characterize the corrective approach, largely shifted towards a preventive maintenance mindset with scheduled maintenance activities aiming to prevent equipment failure from occurring (Alsyouf 2006). Instead of replacing components after failure, critical parts of the machinery were substituted at predetermined time intervals or after a fixed number of operating hours, regardless of the actual status of the component.

However, with the globalization of the economy increasing international competition followed and the capital cost of the production systems grew larger resulting in high costs for replacing equipment. In order to maximize the utilization of assets and minimize the unnecessary substitution of components the condition based maintenance type (CBM) was developed. Starting within the American defense and aviation industry, the CBM approach gained ground in the 1970s (Prajapati, Bechtel & Ganesan 2012). In contrast to the preventive approach, the condition of the component initiated maintenance. By monitoring equipment and machinery with methods ranging from simple visual inspection to continuous computer-based analysis of real-time process data, the current state of the production system was closely observed. When critical parameters exceed predetermined intervals maintenance activities were initiated.

PdM can be described as the next level CBM; maintenance activities are determined by analysis of the historical process data and forecasts based on data trends (Swedish Standard Institute 2001). By closely monitoring any deviation of the critical parameters (that can be based on for example vibrational, thermal or tribological measurements) potential faults can be detected and prevented at an early stage. Hence, the main difference from CBM is the trend analysis - by analyzing historical data instead of only looking at the current state greater knowledge and control of the equipment status can be obtained (Mobley 2002). The PdM approach to maintenance is becoming an important tool for manufacturing and producing industries in order to increase asset utilization and reduce downtime and unnecessary maintenance activities. By continuously monitoring the equipment and analyzing historical data trends the remaining lifetime can be estimated. The main benefits of using a PdM approach are the possibility to detect potential faults at an early stage and the opportunity to reduce the operation costs by optimizing the scheduled maintenance activities. Furthermore, by closely monitoring the condition of the components, unnecessary preventive actions can be avoided and the equipment lifetime can be prolonged (Hashemian 2011).

2.3.2. Corrective maintenance

Corrective maintenance, also known as “run-to-failure”, regards the maintenance that occurs when a system has failed (Wang 2002). Most often, corrective maintenance is considered unwanted. However, if the importance of an asset is low or no value creation is connected to the concerned system, this type of maintenance can be accepted. According to Swedish Standard Institute (2001), corrective maintenance is defined as "maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function".

2.3.3. Preventive maintenance

Swedish Standard Institute (2001) defines Preventive maintenance is defined as “maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item”. Preventive maintenance is divided into two categories; Predetermined maintenance and Condition based maintenance.

2.3.4. Predetermined maintenance (PM)

Preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation is called Predetermined maintenance (PM) (Swedish Standard Institute 2001). This type of maintenance demands equipment with fairly predictable patterns of failure in order to be beneficial. The complexity of new equipment has however increased rapidly the last decades and sequentially patterns of breakdowns have gotten harder to identify. In such cases it is difficult to increase a system’s reliability by implementing predetermined maintenance without “over-maintaining” at too large costs. (Mobley 2002)

2.3.5. Condition based maintenance (CBM)

CBM relates to the maintenance activities initiated by the condition of a system. Swedish Standard Institute (2001) defines it as: “preventive maintenance which include a combination of condition monitoring and/or inspection and/or testing, analysis and the ensuing maintenance actions”. In this type of maintenance the condition of a system is monitored and analyzed before any maintenance is initiated. Only when monitoring reveals any risks action is taken. Physical inspection is an example of a simple, yet a potential CBM activity. It could for instance be a technician reporting a service request based on changes in the physically notable attributes of a machine, e.g. sound, smell or temperature. More advanced CBM setup requires sensors and other devices for continuous monitoring of equipment condition. This can be costly and it is often not used everywhere in a system but prioritized at more critical areas. Though, as the price of equipment and sensors constantly reduces, CBM continually gets more accessible. (Mobley 2002)

2.3.6. Predictive maintenance (PdM)

In this report, PdM is defined as "Condition based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item" (Swedish Standard Institute 2001). Thus, historical data is utilized to detect trends of a system's behavior in order to predict when it will fail. Then, if a failure trend is detected, time of failure is predicted and ultimately a preventive maintenance activity is scheduled. According to the above definition, visual inspection can be a PdM technique that predictions are bases upon. However, in this thesis, PdM activities that involve the usage of software for analytics of historical data are in focus. Due to the requirement of heavy investments compared to other maintenance types, both in training personnel and equipment, this type of maintenance is commonly implemented in critical systems where availability is important.

2.4. Maintenance strategy

Campbell & Reyes-Picknell (2006) writes that if you know where you are going and have an idea of how to get there, you have a strategy. They continue to describe the usage of the term strategy as a bit ambiguous; it can both relate to a long-term guide of business and to a more detailed directive for management of assets. Slack & Lewis (2011) asserts, however, that the meaning of having a strategy implies stressing the long-term objectives instead of short-term, setting broad, general objectives for the enterprise and being detached from day-to-day work, focusing on the holistic view instead.

According to Kobbacy & Murthy (2008), the maintenance function has during the last decades emerged from being a non-issue to a strategic concern. The perception of maintenance has developed from being a "necessary evil" to an asset and coupled to this it has become an essential strategic concern as well. From the directives of the maintenance strategy, tactical and operational decisions should be derived. According to Campbell & Reyes-Picknell (2006) it is of high importance to complement a strategy with tactical and operational directives as well as aligning it with the organizational business strategy. It can thus be interpreted as the link between the business strategy the operational function (Kobbacy & Muthy 2008; Salonen 2011).

The definition of maintenance strategy is not well defined in the literature. It is often defined as the choice between, or mix of, different maintenance types, such as corrective or preventive. Other definitions state that the maintenance strategy is a means of transforming business priorities into maintenance priorities (Salonen 2011). The definition for maintenance strategy used is in this report is however adapted from Swedish Standard Institute (2001): "management method used in order to achieve the maintenance objectives". Thus, it is interpreted as the overarching guide for decision-making regarding maintenance operations. This is aligned with the opinion of Tsang (2002) who claims that a maintenance strategy should serve as support regarding strategic issues, e.g. outsourcing of maintenance activities, allocation of resources and prioritization of operations.

As mentioned above, a maintenance strategy can, and generally should, include a mix of different maintenance types. The relationship between the most significant maintenance types in this project is illustrated in a maturity matrix, shown in Figure 5. This representation highlights the differences in terms of capability to detect equipment malfunction (Alsyouf 2006). In order for an organization to be able to work with PdM it must be able to handle both PM activities, for instance organizing prescheduled activities, and CBM activities, such as evaluating machine condition through online monitoring. Without these abilities, PdM is not possible to implement. Therefore, PdM is seen as the most mature maintenance type, while Corrective maintenance on the other end is considered the least mature (Diamond & Marfatia 2013).

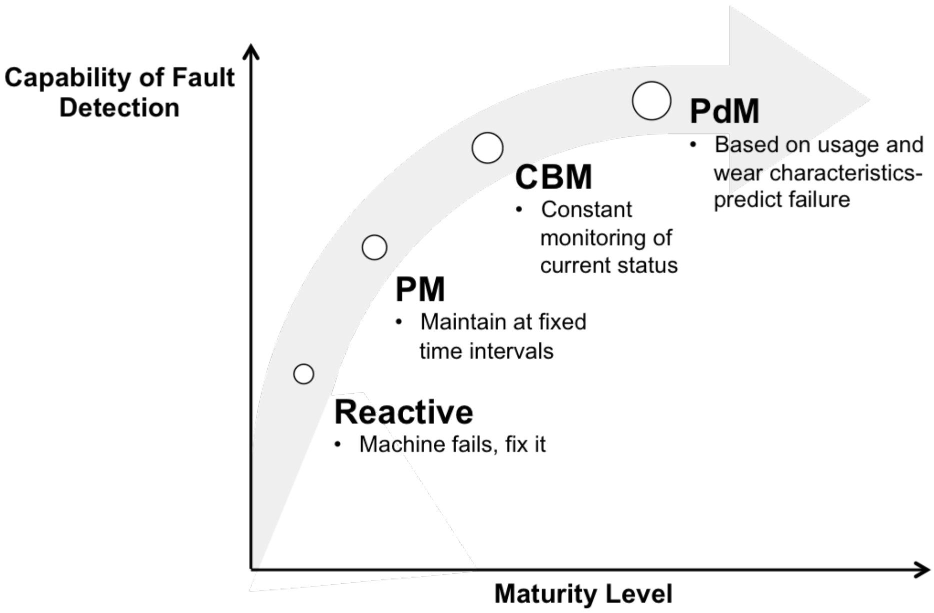

Figure 5: The representation of the four maintenance types in terms of maturity level and capability of fault detection. Based on Diamond & Marfatia (2013).

2.4.1. Reliability Centered Maintenance (RCM)

As means for implementing maintenance strategies, different maintenance frameworks including both strategic aspects of maintenance as well as practical have emerged. These frameworks are in this report called maintenance concepts. Reliability Centered Maintenance (RCM) is a concept that can be, simplistically, described as a mix of preventive, corrective and PdM. It is based on a systematic process to determine required maintenance actions, from a functional aspect, for a system to maintain its reliability. It is a widely utilized maintenance concept that focuses on the function and reliability of critical equipment, by targeting the root cause of failures (Hinchcliffe & Smith 2003).

As mentioned earlier, maintenance has developed rapidly the last century. When Predetermined maintenance first was introduced, equipment failure was assumed to be time-based. Thus, the probability of failure would increase as the asset got older. Three types of failure curves were identified; the bathtub curve, the wear-out curve and the fatigue curve, represented in the left column of Figure 6. This supported the notion that a strategically scheduled overhaul could prevent failure from occurring (Siddiqui & M. 2009). Later research has revealed that only a fraction of all failures follows the age-related failure curves. (Hashemian 2011). Hence, the large majority of failures would appear independent of age, for which time-based maintenance is not the optimal solution. These are represented by three additional failure curves, the initial break-in period curve, the random curve and the infant mortality curve, presented in the right column of Figure 6.

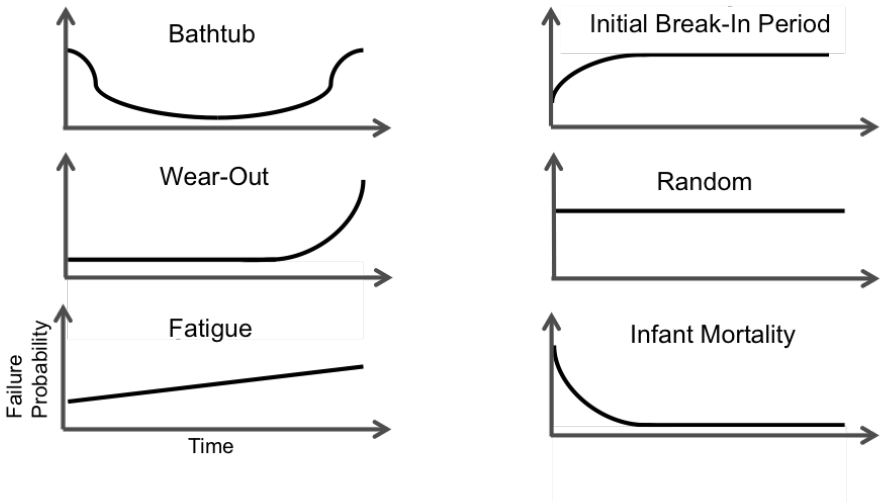

Figure 6: Failure curves, based on Hashemian (2011).

These findings exposed a need for a new way to approach equipment failures. As the first industry to confront the problems of multiple failure patterns and increasing complexity in maintenance decision-making, the aviation industry in the United States started to develop a framework. It came to become a comprehensive decision-making process, later known as RCM.

RCM is based on the idea that by focusing on the consequences of failure and the use of preventive maintenance tasks, a more efficient lifetime maintenance and logistic support program can be developed (Anderson & Neri 1990). By focusing on the important functions of the system, avoiding unnecessary activities, cost is eliminated (Rausand 1998). This is achieved by the use of a number of different RCM related tools and methods, such as criticality assessments and FMEA, which are described further en later sections of this report. According to Hinchcliffe & Smith (2003), RCM consists of four main features; defining system function, identifying potential loss of function, prioritize functions and identifying candidate actions.

The general view of RCM is that, if implemented correctly, a number of positive effects can be achieved. For instance, safety and environmental hazards can be reduced, operating performance increased and maintenance can become more cost effective. The thorough process that RCM is creates a better understanding of the system that not only results in higher reliability, but also enables innovation and further improvements (Hinchcliffe & Smith 2003; Moubray 1997; Siddiqui & M. 2009).

2.5. The scope of a PdM program

It is important to note that PdM should not be seen as a replacement to other maintenance types. The need for preventive and corrective actions will not be completely eliminated upon the implementation of PdM; however, a PdM program can serve as a powerful complement to the existing maintenance strategy. PdM relies on a combination of technology and human skill. The process of predictive analytics includes using all forms of current and historical performance and diagnostics data in order to schedule the right maintenance activities at the most cost-optimal time. The core idea of PdM is to perform the necessary maintenance activities at the critical equipment at the right point in time, instead of relying on pre-scheduled maintenance activities. Basically, all maintenance activities initiated to prevent failures based on predictions can be labeled as PdM, but how the predictions are produced varies and ranges from very simple and analogous methods to highly advanced and technological ones. The basic premise, however, is that this prediction should be based on regular monitoring of the condition of the machine (Mobley 2002)

Traditionally, PdM programs are focused on maintenance optimization efforts. However, the scope of predictive analytics can be extended to include more than maintenance management. Since PdM relies on constant equipment and process monitoring it is closely linked to plant optimization efforts and risk and reliability improvements. Vibration monitoring and thermography are commonly seen as typical PdM methods, which are indeed true, but as Smith (2001) points out – PdM is much more than that. He refers to PdM as a philosophy with objective to improve productivity, quality and overall effectiveness of the manufacturing and production plants. A comprehensive PdM program should focus on minimizing downtime, reduce the amount of redundant preventive and corrective actions and furthermore, increase the useful life of critical equipment and minimizing the systems total life-cycle cost (Mobley 2002).

In terms of plant optimization, PdM techniques can provide valuable information regarding the optimal production practices. It's common that the actual plant operation exceeds the originally designed limitations, largely due to increased competition that raises the demand on production rate (Mobley 2002). In cases when the original design is insufficient, the information gathered and processed by the PdM program can be used to produce reports that identify optimal production procedures and potential need for retrofitting actions. The data can be used to analyze the effect on the production system for different operating modes. This is a valuable capability since it provides a solid basis for decision-making regarding new investments. Further, it gives the opportunity to avoid costly corrective maintenance activities and reduction in useful life of critical equipment (Mosher 2006).

An effective PdM program provides the maintenance unit with an increased control of the system and knowledge of the plant performance. The predictive analysis is thus also a powerful tool for improving plant reliability. If properly designed, the PdM program can detect any deviation form expected operation conditions of critical components. This capability decreases the likelihood of catastrophically failure and quality issues related to the final plant output (Mobley 2002).

The main benefits of a PdM program includes (Carnero 2006):

- A higher degree of control of the production system which leads to increased equipment availability and decreased downtime
- The possibility to detect and prevent equipment degradation at an early stage which reduces the need for costly corrective actions
- The ability to perform maintenance activities at the right time, leading to increased utilization of components
- Increased plant safety and reliability of the production system
- A powerful decision-making tool which provides the capability of evaluating the cost related to different operation modes

Compared to a traditional preventive maintenance program the amount of instruments needed for equipment monitoring is often large. To be able to interpret data trends the skill level and experience required of the staff is higher as well. Thus, a PdM program generally requires a higher initial cost compared to a PM approach due to the additional investments in hardware, software and educational efforts needed (Mobley 2002).

During the early stages of operation, the PdM program generally produces more alarms and triggers more work orders than conventional PM programs and other corrective methods, according to Mobley. This effect tends to decrease after the run-in of the program, but the benefits in terms of reduced cost of maintenance might not be seen at the initial phase (Mobley 2002).

2.6. Framework for PdM implementation

It is important that the focus of the PdM program is directed at the right equipment and equally important that effective decision-making procedures based on the predictive analysis are in place within the maintenance organization (Mobley 2002). In general, the process of initiating a PdM program can be divided into the following five main steps: (Groba et al. 2007; EPRIGEN 1998)

- Identification of significant equipment and indicators
- Measuring of the indicators
- Modeling of the indicators
- Forecasting of the indicators
- Developing effective decision-making procedures

In this case, indicators refer to physical parameters that indicate wear and aging of the concerned equipment. These five steps are discussed in detail below.

2.6.1. Identification

As mentioned, a PdM program usually comes with a rather significant initial cost, which means that not all equipment can be maintained cost-effectively using PdM. Successful programs are focused on the most critical equipment and enable the maintenance organization to quantify the cost-benefits of the system. Thus, the initial step of setting up a PdM system is to define what machinery and equipment is to be included in the scope of the program. This decision should be based on the results of a criticality analysis (Groba et al. 2007).

2.6.1.1. Criticality analysis

Equipment criticality can be seen as an assessment of the importance of the concerned equipment to the purpose for which it is being utilized. Criticality should define the priority of equipment that is used for allocating the maintenance budget. Components that will have a sever impact on the production output in case of failure will be associated with a high criticality. However; assessing the impact of failure to production is a complex tasks that involves several key factors such as cost of equipment, failure frequency, cost of replacement, maintainability of equipment and safety issues associated with equipment failure (Gomez de Leon Hijes & Cartagena 2006).

A team of expert with great knowledge of the concerned system should perform the criticality analysis. Gomez de Leon Hijes & Cartagena (2006) suggests that all relevant equipment should be divided into the following four different classes that are defined as follows:

- Class 1 – Equipment is essential to the process and must be online for continued plant operation; loss of this equipment will lead to an outage.
- Class 2 – Equipment that is critical to the process and that would severely limit the production capacity if lost.
- Class 3 – Equipment that has a high impact on maintenance cost but dose not severely limits the production capacity if lost.
- Class 4 – Other plant equipment with a high frequency of failure that affects the production or maintenance costs.

Hence, all plant equipment that, if lost, would have a serious impact on the output and efficiency of the plant should be included in this compilation of equipment. However, there are several different methods and frameworks for how a criticality assessment should be carried out. For example, the multi-criterion classification of critical equipment (MCCE), is used for calculating a criticality index based on several factors related to equipment failure that are unique to the concerned process and company. Each factor is associated with a weight, indicating its relative importance to the other factors (Gomez de Leon Hijes & Cartagena 2006). The ABC criticality-rating method on the other hand, relies on an activity based costing (ABC) analysis, which is a method for determining the actual cost of necessary activities to produce a certain product. Each potential failure mode for all plant equipment is analyzed and the calculated associated cost determines the criticality of the equipment (Sondalini 2004).

Regardless of how the analysis is carried out, the key-take away is that the resulting priority should be determine what equipment is to be included in the PdM program (Groba et al. 2007).

2.6.1.2. Failure Mode and Effect Analysis (FMEA)

The next step is determining what techniques should be used for monitoring equipment conditions. This requires knowledge of what indicators characterizes each of the equipment types that are included in the program; thus, the Failure Mode and Effect Analysis (FMEA) is an important tool in this process. The objective of a FMEA is to detect and identify potential failure modes of system components for each functional failure identified. Furthermore, appropriate actions needs to be determined in order to minimize the effect of these failures (Stamatis 2003).

There are several different methods that provide a structured way of performing this analysis. In general, an effective method includes a systematic process to evaluate all potential failures that could occur and assesses the severity of the impact of the system operations for all scenarios. The analysis is normally conducted during the design and development stage of the system or product. The output of the FMEA provides the knowledge needed to minimize the consequences of potential failures and increase the product or system reliability (Stamatis 2003).

2.6.2. Measuring the indicators

After deciding what equipment to include in the scope of the PdM program and gathering information of the corresponding failure modes, the next step is to identify the optimal measuring technologies. A comprehensive PdM program requires collection of data through a range of measurements. The operations and maintenance guide compiled by the US Department of Energy (US Department of Energy 2010) lists and presents the most significant methods and techniques, which are included in the majority of the most successful PdM programs within the energy sector. Four of these techniques are presented in section 0, a deeper evaluation of the optimal measuring techniques lies outside of the scope of this thesis.

2.6.3. Modeling and forecasting of the indicators

This step focuses on the process of performing analysis of the acquired data and the generation of relevant trends. According to the standards, the predictions of a PdM program can basically be performed using pen and paper. However, there is a wide range of digital solutions available that performs predictive analytics based on advanced algorithms. There are three main types of models that are used for making predictions of failure; empirical, experienced based and physical models. The idea of all three approaches is to create a dynamic representation of the system that corresponds to normal operation conditions of the asset for each input parameter (Roland Berger 2014). This model is constantly compared with the actual operation in order to detect any deviation that might indicate the onset of equipment deterioration.

The empirical approach is based on historical data from the concerned asset, which is used to construct a model that represents the equipment behavior. Experience based models are created in a similar manner but uses aggregated group data that is acquired from multiple related assets. The modeled normal behavior is based on multiple signals, which creates the possibility of early fault detection. Physical models on the other hand, are constructed using a completely different technique. They are based on fundamental engineering principles and describe how the system theoretically should perform under certain conditions (Roland Berger 2014).

2.6.4. Decision-making

Establishing an effective process for how to react to the predictions is equally important as making the actual predictions. In order to implement and maintain a successful program, a clearly defined set of processes for the PdM workflow should be established. Maintenance activities should be based on the gathered data and the constructed models, which requires a standardized and well-established decision-support system (Roland Berger 2014).

Furthermore, it is important that the decision-makers understand how the process of implementing a PdM program usually works. According to Mobley (2014), in most cases the PdM program initially leads to higher percentages of corrective activities since several operational issues are detected during the first months. In many of the cases when the PdM programs have been aborted, the management teams are too quick to judge the program inefficient. Thus, a strong managerial commitment and an understanding of this process are needed for a PdM program to prove useful (Mobley 2002). As with any organizational change, the support of upper management is vital to the success of the implementation of a PdM program. A transition to a predictive type of maintenance often involves a higher focus on data handling and new information exchange processes for the maintenance crew. Mobley points out that in most cases when PdM has been unsuccessful, the management team has focused on the necessary equipment and software needed but failed to acknowledge the importance of educating the staff on the new system (Mobley 2002).

At larger industrial production facilities it is common that parts of the maintenance operations are outsourced. In case of PdM, outsourcing might be beneficial due to the rather high skill level and expertise required by the maintenance staff to interpret the predictive data accurately. However, there is still need for qualified staff with knowledge about how the PdM program functions within the company. The maintenance unit needs to be able to evaluate the resulting recommendations of the PdM program and make sound decisions regarding what actions are to be taken (Carnero 2006).

2.7. Monitoring techniques

As mentioned, PdM is a development of CBM as condition monitoring is to a great extent the foundation for making predictions. In this section, the reader is introduced to four of the most commonly used monitoring techniques within the power industry according to the US Department of Energy (2010). Note that these concepts are not new, however, the way these types of measurements are performed can vary from using simple handheld devices to advanced digital software.

2.7.1. Vibrational analysis

Many consider vibrational analysis as the foundation of every PdM program. A vibration can be defined as a periodic motion or a motion that repeats itself at a given time. Any moving machinery generates a vibration profile, regardless if its operational pattern is rotation, reciprocation or linear motion. Hence, the key to a useful vibrational analysis is the ability to distinguish a normal from an abnormal vibration profile. The resulting profile of vibration measurements is normally very complex since several sources of vibration add to the final composite curve. However, specific malfunctioning equipment results in abnormal and complex but still recognizable vibrations. If monitored over time, the normal vibration profile of the equipment can be obtained - any unexpected deviations (changing load etc. may also cause changing frequency and amplitude) can be isolated and compared to vibrational profiles of common failure modes (Mobley 2002).

The type of instruments highly depend on the operational conditions of the concerned equipment, but in all cases some form of transducers are required to measure the vibration by converting the mechanical motion into electrical signals. In the power industry, vibrational analysis is most commonly focused on the turbines and other critical rotational equipment. Unbalance, mechanical looseness and misalignment are just a few faults that vibration analysis can be of assistance identifying. These measurements can be performed manually using handheld devices but digital solutions are commonly in place within the power industry. Successful PdM systems include continuous measurements and on-line performance monitoring of the equipment (US Department of Energy 2010).

2.7.2. Thermography

Infrared (IR) thermography is a non-destructive testing technique used to monitor the temperature profile of the system equipment. Deviation in the equipment's temperature is often a result of component malfunction. For example, corrosion in electrical connections can lead to an elevated temperature due to increased electrical resistance - by closely monitoring the temperature profile this type of malfunction can be detected at an early stage and potential failure can be avoided. All objects at temperature greater than zero Kelvin radiates some amount of IR energy that is proportional to the actual temperature of the object. This energy does not lie within the visible spectrum and cannot be seen by the human eye, but by using instrument equipped with IR detectors the radiation and the corresponding temperature profile can be analyzed (Mobley 2002).

There is a wide range of instruments that can be used for IR detection and thermography, but for applications within the power industry these instruments can be divided into two groups – imagers and IR cameras with radiometric capability. The imager provides a visual representation of the IR radiation but lacks the ability to analyze these results and present actual temperatures. This technique is adequate when temperature deviation is sufficient to detect possible faults, but in cases when the actual temperature is of importance to condition monitoring, radiometric capability is needed. This group of equipment visualizes the radiation and also provides the tools to render and analyze the actual temperatures. These analyses can be performed using handheld devices but fixed systems for continuous monitoring dose also exist. (US Department of Energy 2010)

2.7.3. Lubricating oil analysis

There are three main types of techniques for monitoring the lubricating oil; analysis of the physical conditions, identification and analysis of contaminants and wear particles analysis (US Department of Energy 2010).

Viscosity is one of most significant psychical parameters of the lubricant - to low viscosity will result in "weaker" oil and increase the risk of metal-to-metal contact, while to high viscosity results in thickening of the oil and may reduce the lubricating effect by impeding the flow of oil. Contaminants such as for example water and coolant may also affect the oil film and increase the risk of contact between the moving machine components (National Aeronautics and Space Administration 2000). Wear particle analysis is the process of analyzing machine particles that might exist in the lubricant due to machine wear. This makes it possible to monitor the machine condition and identify and prevent wear before actual fault occurs.

Traditional analysis performed in laboratories are costly and requires skilled personnel, but recent development of spectrographic analysis using microprocessor-based systems has automated most of the analytic process and reduced the costs. Furthermore, there are instruments that can be used for quick on-site analysis that will give an indication of potential oil problems and information of the oil condition, which can be used to determine need and time-intervals for oil change (Mobley 2002). By frequent sampling and monitoring of the historical dataset, lubricating oil analysis can be an important part of a PdM program. Data trends can be used to determine the most cost effective time for oil change base on the actual oil condition.

2.7.4. Ultrasonic analysis

The ultrasonic measurements are focused on analyzing high frequency sound patterns that cannot be detected by the human ear. Most rotating machinery emits some ultrasonic sound, which, similar to the vibration profile, reflects the operation condition of the equipment (Mobley 2002). Furthermore, ultrasonic measurement devices can be used to detect leaking valves and pipes since the turbulent fluid flow through small openings creates high frequency sound waves. The majority of the available ultrasonic measurement equipment is designed for at-point-use and are normally not capable of storing data. However, some transmitters that can be inserted in the piping system and used for monitoring of leakage do exist (US Department of Energy 2010).

2.8. Digital solutions

In this thesis, three categories of monitoring and analytics software solutions have been defined:

Stand-alone condition monitoring solutions: Refers to separate, dedicated software used for example solely for vibration monitoring. There is a wide range of different solutions with different sets of capabilities.

Performance monitoring: Includes all type of software that can perform simple calculations and produce trends that is used for monitoring overall efficiency and other relevant process parameters. In general, power plants are equipped with some sort of solution for basic performance monitoring.

Predictive diagnostic software (PDS): Software that builds models based on historical data and used to detect beginning equipment deterioration. This software can be adapted to virtually any equipment type. PDS solutions represents a new approach to maintenance based on data mining and is gaining ground within the power industry as big players such as Energy, EDF and Exelon are implementing these types of software.

In addition, traditional PdM techniques refers to vibration analysis, thermography etc. performed manually with handheld equipment.

2.8.1. Representation of the data acquisition process

Figure 7 shows the authors' simplified representation of the generic IT-system for a power plant, based on the illustration presented by Roland Berger (2014). The figure illustrates the monitoring process of certain equipment from data acquisition to initiation of improvement effort. Data that describes the status of the equipment (i.e. the indicators) is gathered either automatically or manually depending on the type of measuring equipment used. To secure reliable and accurate values, the role of the human operator in the data acquisition process should be as small as possible, microprocessors allows for automated data gathering which reduces the need for staff and the risk of human errors. In cases when automated measurements are not possible it is important that the data acquisition processes is standardized and preferably performed by the same operator at the same location in order to secure accurate values (Carnero 2006). In power plants, large amount important process data can be obtained from the automation systems. In cases were the data collection process is automated, a Programmable Logic Controller (PLC), which is a digital computer that is used to convert the sensor signals to digital signals (Knijff 2014).

The Enterprise Asset Management software (EAM) refers to the digital software solution, commonly used in capital-intense industries, for storing all forms of asset data, such as output history, work order data, financial data etc. The EAM is a vital tool for optimizing asset operation and maintenance; manual meter readings are commonly entered into the EAM.

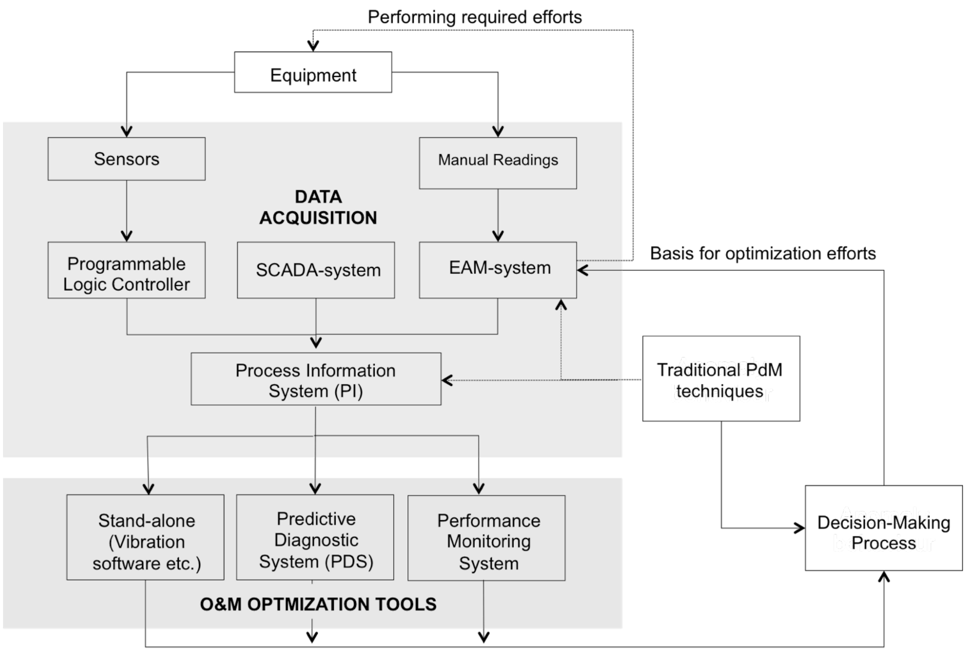

Figure 7: Illustration of the authors' simplified representation of the flow of information for a generic power plant based on (Roland Berger 2014).

The Supervisory Control and Data Acquisition (SCADA) system is a centralized system that acquires data from control systems at different geographical sites (Knijff 2014).

A historian is a software that accumulates data and time-series, which is used as an input for the predictive model and provides the possibility to generate trend analysis (Knijff 2014). Power plants usually have some sort of solution that gathers data from the automation systems and includes a historian for storing data. In addition, these systems are able to perform various calculations and compile reports that go beyond the basic capabilities of the automation systems. These types of solutions are known as Process Information (PI) systems. The downside of the vast amount of data available via the plants' automation systems is that large portions of information might be completely useless to predictive analytics. In order to make accurate predictions based on the measurements the raw data first needs to be cleaned, meaning that helpful data is extracted from the automation systems database (Carnero 2006)

The acquired data from the automation systems, sensors and the EAM are stored in a common database; this data can be used for monitoring and analytics. Furthermore, the data from the traditional measurement is normally transferred to the EAM system and can be used as a basis for trend analysis of equipment condition. In the general case, findings from these analyses are subjected to standardized decisions-making process that describes how the maintenance organization is to act upon the provided information (Roland Berger 2014).

2.9. Justifying maintenance investments

Justifying an investment of a new production line or an equipment update is generally not too difficult - if the capital investment can be recovered within a reasonable period of time, the investment is likely a good one. However, as Alsyouf (2006) points out, assessing the return on maintenance related investments is a quite complex task, simply because the actual monetary value of the benefits of effective maintenance is less measureable than that of enhanced machine characteristics. Economic controllers usually regard maintenance as a cost and the managers are focused at the budget and profit, whilst engineers looks at performance and sees the need for technical improvement. However, money rules, and in order to justify the implementation of a PdM program it is vital to highlight the potential cost reductions that can be provided (Mobley 2002).

Historical data of availability of the concerned equipment, plant performance and failure statistics becomes key resources when the cost of maintenance investments is to be justified. In cases where this type of information is not available it is virtually impossible to illustrate the benefit of maintenance investments and give credit to the maintenance unit. Within the power industry, evaluating the cost of downtime is a complex task since the monetary loss is closely linked to the present market situation. The price of heat and power has a strong effect on the unavailability cost as well as the current fuel costs; these are all rather volatile parameters. Furthermore, the present status of the whole production fleet also decides the cost of unavailability. If a production unit is taken offline, it must be replaced in order for the producer to meet the market demand. The replacing unit that is taken online might be operated with a different fuel type, likely with higher costs since the low-cost facilities are normally operated as much as possible. Key Performance Indicators (KPI) are predetermined, quantifiable parameters that measures the level of success of a certain business-critical activity. What KPI:s are measured and evaluated varies between companies and industries, but the objective of using KPI:s is to help the organization to evaluate the current maintenance policies and to revise the maintenance procedures in order to move towards an cost-optimal strategy (Kumar et al. 2013). Thus, identifying and measuring relevant KPI:s is essential in order to illustrate the value of the maintenance actions and to create a basis for decisions concerning investments in maintenance improvements. "What you don't measure you can't control" (SKF 2005).

2.9.1. Cost benefits of a PdM program

Justifying the PdM program, by measuring the benefits of it in terms of monetary profit, is likely both the hardest and most important part of a PdM implementation. As previously mentioned, the main cost related to PdM is the initial investment in software, hardware and educational efforts. In the general case, the frequency of fault detection usually increases initially due to the effect that the system detects multiple errors at an early stage. After the run-in of the system, the alarm rate goes down and the real benefits of the PdM program can be seen. According to Mobley (2002), the break-even point might be reached after up to 18 months after implementation but this may vary with industry and the scope of the program.

The literature provides several examples of successful PdM programs that have resulted in significant cost cuttings, increased equipment availability and improved reliability. According to the (US Department of Energy 2010) successful PdM can provide savings of 8-12 % compared to a maintenance strategy that relies solely on preventive maintenance. Furthermore, depending on the amount of corrective actions and the material condition, PdM can result in savings exceeding 30 % of the current maintenance costs. In general, the PdM program also results in improvements in terms of reduction in downtime and increased output. According to the O&M-guide, the industrial average savings due to an implementation of a PdM program includes 35 % reduction in downtime and an increase of 20 % in production.

Moreover, it is interesting to note that Roland Berger (2014) highlights that RCM provides the lowest cost of maintenance. In this case, RCM refers to a mix of predictive, preventive and corrective maintenance with the predictive tasks focused on the most critical equipment and reactive actions at the least critical for maximum cost efficiency. Also RCM advocates utilization of proactive measures, such as root-cause analyses.

2.10. Barriers to a successful implementation

Based on the findings in the literature, the following set of general, main obstacles to a PdM implementation has been identified.

2.10.1. Lack of training

A common issue that arises during implementation is a lack of training provided to the operating crew and the dedicated PdM personnel. As already mentioned, PdM relies on a combination of technology and human skill. It is common that software vendors offer the predictive analysts a few days training that provides the basics to the system, but in most cases, additional educational effort is needed to ensure that the analysts are capable to build and evaluate efficient models. Furthermore, it is vital that the maintenance staff understands and accepts the new way of planning and performing maintenance (Mobley 2013).

2.10.2. Lack of trust in PdM technologies

Mobley also points out that one of the major obstacles to a successful implementation is the failure to act on the information provided by the predictive prognoses. Although the program provides the maintenance unit with accurate prognostics based on high quality data, it is common that this information is overruled by the opinions of experienced staff members. Another common practice that limits the potential of the program is that the assigned priority of the predictive recommendations is much lower than for the preventive and corrective actions. This results in predictive tasks only being carried out when there is time left, which makes the predictions useless (Plant Services 2013).

In accordance with Mobley (2002), Roland Berger (2014) also points at the lack of trust in predictive technologies among maintenance personnel. Experienced operators are often skeptic to whether the diagnostics and predictions provided by the PdM system are more accurate than their own assessment of the equipment condition. Due to concerns regarding their own job security, maintenance staff might perceive these technologies as a threat, rather than an aid.

2.10.3. Lack of vision

The introduction of a PdM program is not only the initiation of a new technology, but also a change of strategy and approach to how to perform maintenance. Therefore, if implemented correctly, a PdM program should change the culture, the philosophy and work flow of the maintenance organization. Introducing new techniques without adapting the strategy will likely result in a fitful and possibly failed implementation (Friedman 2012).

2.10.4. Limitations in the range of application

A PdM approach can be relatively easily implemented at plants for which maintenance activities are focused on a small set of critical components, such as wind farms. However, more complex production system that includes multiple assets that are considered as critical to operation poses higher demands on the predictive system. According to the Roland Berger report (2014), implementing PdM at these types of facilities is challenging with the existing software and technology. Difficulties with implementation might also arise in cases of assets that performs multiple operations and are supported by a large amount of human interaction, which is often the case in manufacturing facilities. This makes the processes of determining normal equipment behavior and setting alarm limits more complex, since a wide range of operating modes is to be supported (Roland Berger 2014).

2.10.5. Difficulties in justifying the need of maintenance investments

As already discussed; motivating investments in maintenance is a rather complex task. As with any investment, a solid business plan including a cost-benefit analysis should be the basis for decision-making, but in the case of maintenance investment such a plan might be difficult to create. Reluctance to costly investments that has a severe impact on maintenance budgets is common in the manufacturing industry as well as in the process industry, due to low margins and high cost pressures (Plant Services 2013).

3. Methodology

This section describes the work process in detail and explains relevant terminology, the choice of research methods and frameworks that were used throughout the project.

3.1. Research strategy

Yin (2003) discusses benefits and problems of different research methods. The choice of research method should be based on three conditions; the form of research questions, the need for control of behavioral events and if there are focus on contemporary events. A case study is based on an analysis of a limited number of units in their natural condition. Furthermore it should be focused on a contemporary phenomenon within a real-life context and the behavioral events studied should generally not be manipulated. Neale et al (2006) describes the case study as a method appropriate when something unique or interesting is to be told. Further, several sources of information can be utilized in a case study, such as documents, interviews and observations, to provide a complete story (Neale, Thapa & Boyce 2006). Yin (2003) emphasizes that different research methods can be combined, e.g. a case study can include surveys and historical research and vice versa.

A case study is chosen as the main research method for this project, since the research considers a contemporary set of events, over which the researchers has no control over. In this situation, a case study is an appropriate research method according to Yin (2003). In addition, several methods for data collection was used in this project as well. Inspired by the structures proposed by Neale et al (2006) and Jonker & Pennik (2010), following process of conducting the research has been applied:

1) Plan
   a) Identify problem
   b) Identify stakeholders to be involved
   c) Identify sources of information
   d) Define time-plan
2) Develop research instruments
   a) Literature review
   b) Questionnaire
   c) Benchmarking tool - CNA
   d) Interviews with stakeholders
   e) Archival research
3) Collect data
   a) Distribute questionnaire
   b) Perform stake holder interviews
   c) Perform benchmarking
   d) Literature review and archival research

4) Analyze data

  a) Analysis of questionnaire responses
  b) Analysis of benchmark
  c) Analysis of literature review and archival research
  d) Synthesis of analyses

5) Disseminate Findings

  a) Present results
  b) Report

3.2. Project initialization

The initiating problem to this project was defined in two research questions. In order to answer these questions, the four methods of data collection listed below were used. These are presented in detail in the following sections of this chapter.

- Literature review
- Situation analysis
- Benchmarking
- Archival research and case studies

Figure 8 shows the data sources used and the analyses conducted in order to answer each of the research questions. As shown in the figure, the findings from the archival review and the literature review were used in order to identify possible barriers to a successful PdM implementation. Furthermore, to assess the current alignment with PdM all four data sources were used. The situation analysis together with the benchmark gave a wide picture of the current maintenance maturity, which was compared with the findings in the literature. In addition, PdM related practices that were discovered in the archival review were taken into account as well.

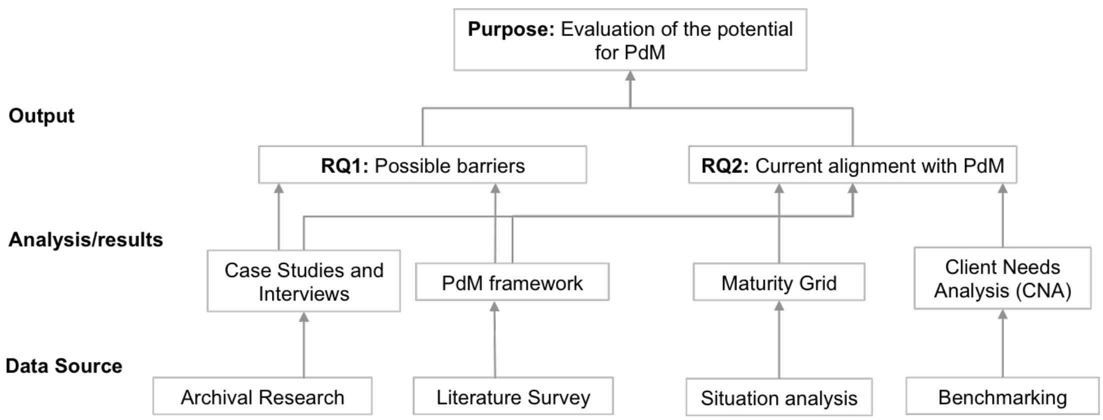

Figure 8: The figure illustrates what source of data and which analyses were used to produce the answers to each of the research questions.

Lastly, a time-plan was produced in form of a Gantt-chart, where important milestones were noted and a timeframe was established.

3.3. Literature review

To gain appropriate knowledge of the theoretical background to the project a literature review was conducted. The initial aim of the review was to get a holistic grasp of the terminology and concepts relevant to the project, such as maintenance strategies and the development and application of different maintenance types. Further on, the review was more focused on the area of PdM, where the objective was to find state of the art literature from both academic and industrial angles regarding all aspects relevant for an implementation of the concept. This served as base for the benchmarking of external PdM practices and the internal analysis of the potential for implementation of PdM. The search for information was mainly performed on databases available through Chalmers library but also in physical libraries and on other forums on the Internet.

Literature was mainly searched for in the following databases:

- AccessEngineering
- Books24x7
- Emerald
- IEEE Xplore: digital library
- IET Digital library
- NASA Technical Reports Server
- ProQuest Platform
- Scopus
- Web of Science

Different combinations of the following keywords were used:

- Maintenance
- Predictive
- Condition Based
- Strategy
- Production
- Measurements

3.4. Situation analysis

The objective of the situation analysis was to evaluate the current status of the maintenance operations at each plant within the scope of the study. Moreover, the aim was to identify production units were the PdM type was already in place to some extent. The output of the situation analysis was a mapping of the current status of the maintenance operations at each production site. This mapping was also used as a basis of decision-making of what plants were to be selected for the benchmarking in order to obtain a wider knowledge of Fortum's current alignment with PdM practices.

The following steps were included in the situation analysis:

- Literature review
- Interviews
- Compilation of the questionnaire
- Analysis of KPI:s

These steps are described in detail below.

3.4.1. Interviews

The interview process is often divided into three categories; structured, semi-structured and unstructured interviews. In a structured interview the same set of predefined questions, each with a number of pre-stated answers is asked to all respondents. For the interviewer there is little room for variation due to the objective to conduct every interview in an as similar manner as possible. The impact of the interviewer on the responses should thus be relatively low. The main strength for the structured interview is the ability to collect standardized, quantitative answers time-efficiently (Fontana & Prokos 2007). Unstructured interviews are on the other hand of a more qualitative nature and can be described as a guided conversation, where emerging questions are included and discussed as the interview proceeds. Therefore, it can give a breadth of answers and result in a more nuanced set of data than a structured one. The third category is the semi-structured interview, which is usually based on pre-defined, open-ended questions and conducted at a pre-planned time and location. According to Dicocco-Bloom & Crabtree (2006) it is the most common interview format for qualitative research. A semi-structured interview is hence more appropriate when the aim is to understand a complex subject in a structured manner, rather than collecting strictly categorized, quantitative data (Dicocco-Bloom & Crabtree 2006; Fontana & Prokos 2007).

To initially achieve a holistic picture of how the maintenance organization of Fortum functions, semi-structured interviews was held with key persons within the company. The aim was to find persons to interview from every concerned division of Fortum; hydro, heat and nuclear. Through these, a better understanding of similarities and differences for maintenance procedures of the different divisions was to be achieved. Since there was only one plant of interest within the Nuclear, it was decided to postpone this interview and to focus on the more complex divisions Hydro and Heat. Interviews were therefore conducted with Fortum employees, conversant of Hydro and Heat. These interviews were focused on the present practices of Fortum as well as on potential improvement areas. In order to gain insight on the topic of PdM techniques within the power industry, interviews were conducted with engineers from Fortum’s own consulting agency, Power Solutions that has vast experience and knowledge of maintenance optimization projects. Furthermore, to obtain an outside view from another industry, interviews were conducted with researchers focused on CBM and PdM projects within the automation industry.

The interviews acted as a complement to the knowledge gained through the literature review. The combined knowledge of the review and the interviews formed a foundation on which the further work of the project was built, especially the situation analysis. Before entering the next project phase Fortum’s maintenance cooperation unit, the Maintain X-Country Team, was consulted and the feedback from team was considered during the development of the questionnaire.

3.4.2. Questionnaire

The main objective of the questionnaire was to define the status of the maintenance organization at each plant and the results would later be used to determine which plants to evaluate further at the benchmarking stage. To achieve this, the questionnaire was compiled and distributed to persons responsible for the maintenance operations of all production sites within *Heat* and *Nuclear*. The questionnaire was also used as a base for structured interviews with the area managers whom are responsible for the maintenance operations within *Hydro*.

When designing a questionnaire it is crucial to avoid any ambiguity by formulating short and precise questions. It is also important to always have the context of the study in mind and adapt the use of language to it (Bohgard et al. 2008). The structure of answers can be categorized in two subgroups; open-ended and close-ended. The latter refers to having predefined answers of which the participants chooses which one, or ones, to agree with. This sort of data are easily handled and analyzed due to the standardized alternatives. They can however make the respondent feel that they have to choose an alternative that does not fully comply with their view. Open-ended answers, where the participants can formulate the answer of their own, are on the other hand more time-consuming to analyze. However, this alternative is beneficial when the researcher is unsure of what aspects that are of importance to enquire about, or the possible answers too many (Bohgard et al. 2008).

Based on above stated facts, the questionnaire included both open-ended and close-ended questions. The current plant status was evaluated by assessing the maintenance organizations in terms of two parameters, predictive and data collection capability. These parameters were defined by the authors and based on the findings in the literature review these factors were considered vital for successful PdM. The definition of each parameter is presented below.

Predictive capability

In this case, PdM was considered the most evolved type of maintenance. The questions in this part of the questionnaire were mainly focused on how production measurements were used in order to plan and perform maintenance at each plant. Each alternative answer was intended to represent the characteristics for corrective maintenance, PM, CBM and PdM.

Data collection capability

The data collection capability refers to the production measurements that are currently being gathered and how organized the processes of data acquisition and data processing is. By focusing the questions on a set of measuring techniques that are commonly used for PdM an indication of the view on predictive actions at each plant could be obtained (US Department of Energy 2010). The questions mainly concerned how these measurements were conducted and how the data was stored.

3.4.2.1. Testing the questionnaire

Piloting the questionnaire is essential for minimizing the risk of failures, such as misinterpretations (Bohgard et al. 2008). Wilson (2013) gives two examples of how this can be performed; letting an expert analyze the design and the technical relevance of the questionnaire or having a focus group review the readability, terminology and scope of it. To minimize risk of misinterpretation and to test the quality of the questions, an initial draft was constructed and distributed to contact persons from Hydro and Heat. The layout and content of the questionnaire was discussed during interviews and a second draft was developed based on this feedback and used for a pilot test before the final distribution. The CHP-plant in Brista was chosen for the piloting of the questionnaire.

3.4.2.2. Distribution of the final questionnaire

In order to identify and establish contact with the maintenance and area managers in each region the members of the Maintain X-country Team were consulted. The selected respondents were notified and introduced to the project by the members of the team a prior the distribution of the questionnaire. In total, 18 respondents participated in the questionnaire and three area managers within Hydro were interviewed. Only one potential respondent was unavailable to participate in the analysis. The questionnaire tool that is included in SharePoint was used to create the final questionnaire. A workspace was created in SharePoint that could be reached through Fortum's intranet and access to the questionnaire was given to all of the respondents. The question was open to the respondents for 14 days.

3.4.2.3. Evaluation of the response to the questionnaire

The input from the questionnaire was used to construct a maturity grid that included the parameters "Data Collection Capability" and "Predictive Capability". Grading and weighting of the answers of the questionnaire based on important factors found in the literature was used to measure these parameters. This resulted in two scores for each production unit, one regarding data collection capability and one regarding the predictive capability. In order to produce the final grid, each plant was ranked based on their score. The main characteristics of a high scoring profile are listed below, the full presentation of the grading scheme can be found in Appendix A.

Data collection capability - characteristics of a high scoring profile:

- Conducts all concerned measurements for multiple equipment
- Collects data automatically
- Stores the collected data digitally

Predictive capability - characteristics of a high scoring profile:

- Produces trend analysis based on production measurements
- Schedules maintenance activities based on analysis of historical production measurements and trends
- An investigation of the potential for PdM has been carried out at the plant
- Standards for PdM are in place

Note that resulting grid presents a relative comparison of the plants. A high predictive capability does not necessarily mean that the predictive capability is high in relation to the industrial standard. Likewise, a "low" level of predictive capability does not mean that the actual predictive capability is low. It is only the relative values that are of interest in this representation of the maintenance maturity. The questionnaire does also consider a number of aspects found important for a PdM implementation but does not evaluate the complete performance of the maintenance organization. Therefore, a higher position in the plot does not necessarily mean that the maintenance operations of that specific plant is performing better - it does however indicate that it has more experience of handling production measurements and/or is more capable of a PdM implementation.

3.4.3. Analysis of KPI:s

In addition to the evaluation of the current status of the maintenance operations, an evaluation of the performance of each production facility was carried out based on Maximo data. The data analytics software used by Fortum, Qlikview and especially the application “Maintenance Analyze”, was used to produce KPI:s based on this data. In order to gain more knowledge of the current level of proactivity versus reactivity of each maintenance organization, the ratio of corrective to the total number of registered work orders was compiled for each plant. This parameter was defined as a standard KPI in the “Maintenance Analyze” application.

3.5. Benchmarking

By further investigating the current status and potential at three plants, each representing a separate division and segment of the maturity grid, a wider picture of the current alignment with PdM at Fortum could be obtained. Based on the results of the situation analysis Loviisa (Nuclear), Heat South Sweden and Krångede (Hydro North) were selected for the CNA.

The basic purpose of benchmarking is to perform an analysis by comparison with a top-performing object. There are different types of benchmarking; depending on where the boundaries of comparison are drawn. Johnson & Seborg (2007) identifies four main types; internal, competitive, functional and generic benchmarking. In an internal benchmarking, the comparison is to a function within the same organization. Competitive benchmarking regards a comparison with organizations that are in direct competition to one another. In a functional benchmarking, the similarity between the compared objects is the technology and processes. They do not need to be competitors but should be excellent within their own industries. Finally, a generic benchmarking is made by comparison to an international leader whether or not they belong to the same industrial area.

Loviisa achieved the highest score in the maturity grid it was of interest to conduct the CNA and further investigate if and how PdM were used at this plant. Heat South Sweden ended in the lower end of the maturity grid and was thus a suitable representative for assessing the PdM potential at Fortum’s “less mature” plants. Furthermore, Heat South Sweden includes Högdalen, which is a waste-fueled CHP plant of major economical significance for Heat Sweden, making it particularly interesting for Fortum to look closer at Heat South. Moreover, Krångede, which is one of the largest facilities in the north region, was selected to represent Hydro North.

3.5.1. Clients Need Analysis (CNA)

SKF:s Client Needs Analysis (CNA) is an evaluation tool used for assessing plant performance and identifying potential improvements in operations and maintenance activities. SKF has carried out the CNA at over 2000 companies from a wide range of industrial sectors (including +100 within Heat and Power); the CNA-database is thus a powerful tool for benchmarking. The analysis is performed using a questionnaire that consists of 40 questions, which covers the four main areas of SKF:s Asset Efficiency Optimization (AEO) process; Strategy, Work Identification, Work Control and Work Execution. The objective of the AEO is to obtain maximum effectiveness of defined business goals of the concerned plant. Each question is compared to the database and the resulting spider charts (Figure 9) shows the strengths and potential for improvement within these four segments for each plant (SKF 2006).

The output of the CNA can be seen as a snapshot of the current status of the maintenance organization and regardless if the analysis is conducted at one or several of the concerned company's facilities, this gives an indication of the current effectiveness of the maintenance organization. According to SKF (2006), 40 % of the facilities that implements a CBM program without a pre-study of the current performance of the maintenance efficiency report that that the ROI was lower than expected. This stresses the importance of conducting a wider benchmark in order to assess the potential for PdM at Fortum.

The characteristics of each of the "maintenance maturity levels" based on SKF:s definitions is presented below:

Innovating: Inline with best practices, a world-class maintenance organization, largely working with optimizing efforts

Promoting: Maintenance is seen as an asset and a tool for developing a competitive edge, largely working with optimizing efforts

Maintaining: Planning activities are performed in order to avoid failure and surprises; the majority of the activities are focused on stabilizing the operations

Firefighting: A responsive behavior characterizes the maintenance organization as efforts are mainly focused on correcting the results of breakdowns and to stabilize the operations

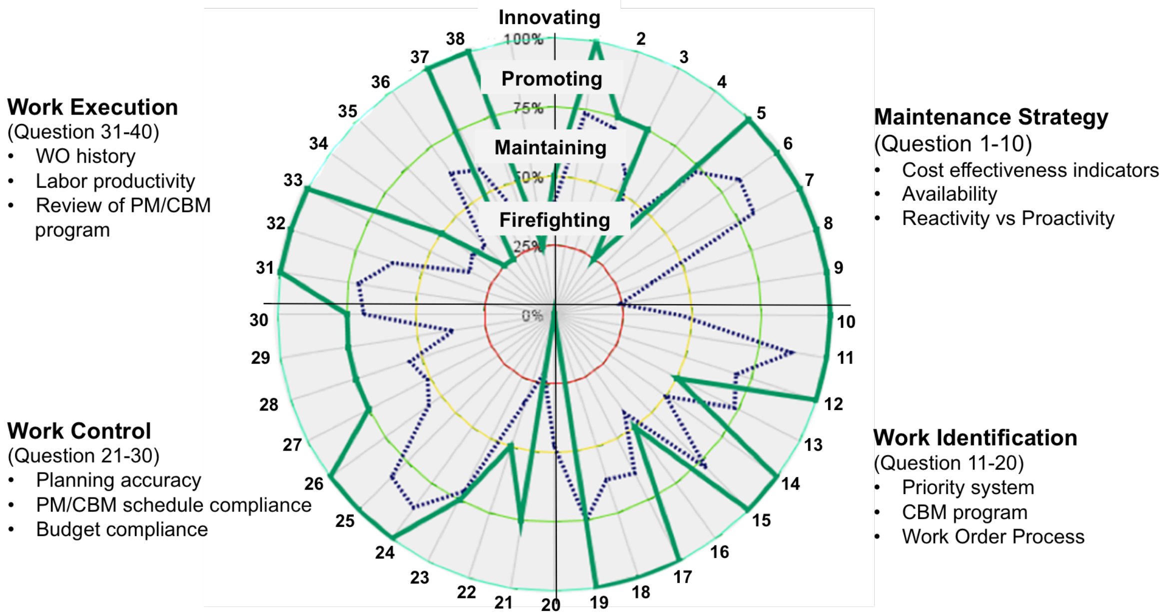

Figure 9: Explanation to the resulting spider-chart that presents the output of the CNA.

3.6. Archival research and case studies

In addition to the situation analysis and benchmarking, studies of previous and ongoing PdM related projects conducted by or within Fortum were analyzed. The main objective of this stage was to detect ongoing projects of interest and to identify requirements and barriers of previous PdM actions. Interviews with Fortum employees with experience of PdM related projects were conducted and archived documentation was obtained from these contact persons. The output of these studies were condensed into a list of the most significant key points, which were used together with the key findings from the literature review during the general discussion of the PdM potential at Fortum.

In addition to the review of internal PdM projects, findings from cases at other companies that where based on material provided by contact persons at Fortum were compiled into a list of the most important external findings.

3.7. Presentation of results

The results of the situation analysis are presented in the maintenance maturity grid together with charts showing the responses of separate questions with purpose of highlighting the differences and resemblances within and between the different divisions. Spider charts showing the results of the CNA with additional comments on strengths and potential for improvements within each of the four AEO categories are presented separately for each plant. Furthermore, a comparison showing the differences and resemblances of each plant is presented using summary matrices. These shows what percentage of the answers are considered to be “Innovating”, “Promoting”, “Maintaining” or “Firefighting” (defined by SKF) within each of the AEO category. Fortum-wide key strengths and weaknesses within these four areas are also listed. A list of the key takeaways from the internal case studies is also presented in the result section. These results are the basis for the conclusion and recommendations presented in the discussion section.

3.8. Time plan

This project and the resulting report is the final thesis of the authors' master studies at Chalmers University of Technology. The project was initiated at January 19th and carried out during 20 weeks, each of 40 hours, throughout the spring of 2015. Two presentations of the results were conducted, one at Fortum for the project stakeholders at the 26th of May and one at Chalmers for the examiner, supervisor and opponents at the 4th of June. In addition to the project related work, two thesis presentations were attended and a thesis opposition was preformed.

4. Results

This section includes the results of the questionnaire. The situation analysis is discussed and additional data based on the answers is presented. Furthermore, the output of the CNA is presented for each of the three facilities together with a summary of the common strengths and potential for improvement identified. The section ends with a summary of the key findings from the internal and external case reviews.

4.1. Situation analysis

The input from the questionnaire was used to construct a maturity grid that included the parameters "Data Collection Capability" and "Predictive Capability". These parameters were measured by grading the answers of the questionnaire, based on important factors found in the literature. This resulted in two scores for each production unit, one regarding data collection capability and one regarding the predictive capability. For further information regarding the framework used for constructing the plot, see chapter 3.4.2.3. The resulting maturity grid is presented in Figure 9. A brief description of a high scoring profile is listed below, the questionnaire including guidelines for grading of each answer can be found in Appendix B.

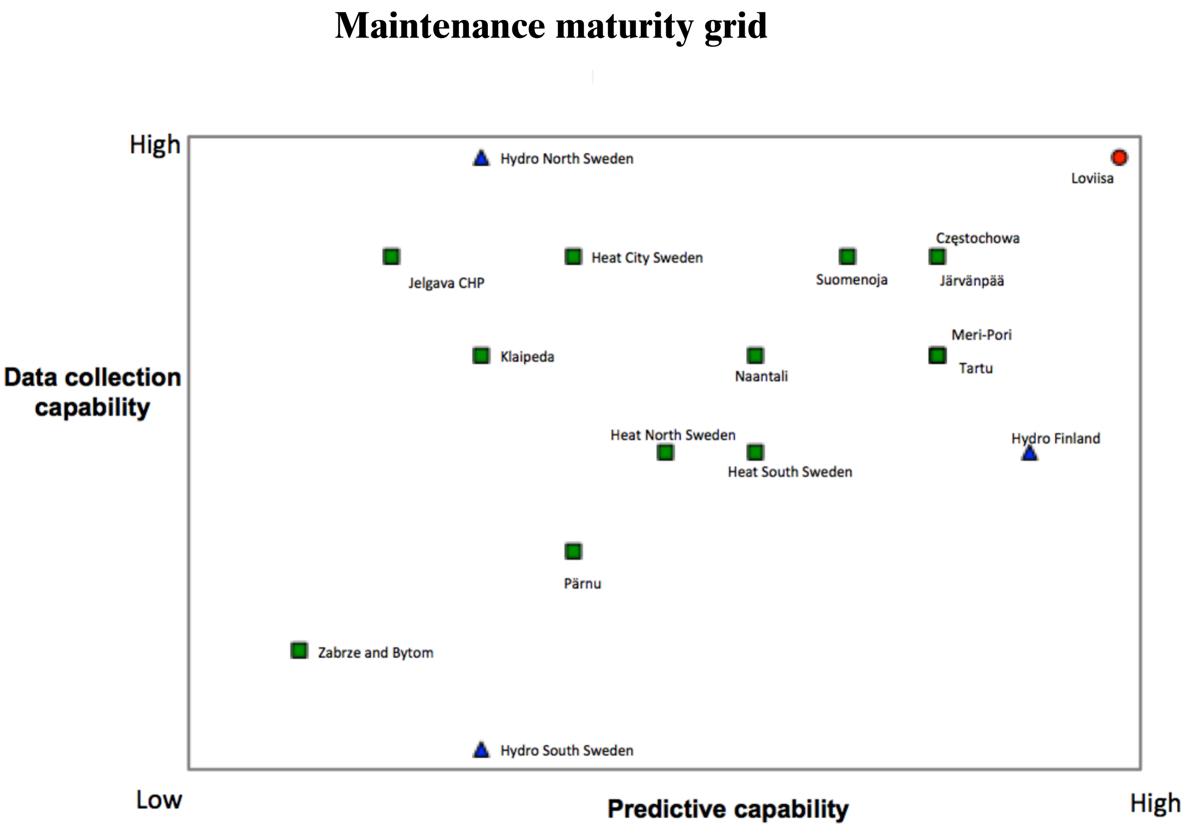

Figure 10: The plot shows a mapping of the maturity level in terms of data collection and predictive capability based on the response of the questionnaire. Note that this is a relative comparison of production units.

4.1.1. General comments on the mapping

Loviisa is considered a state-of-the art nuclear plant and a forerunner in terms of maintenance and reliability operations within Fortum. Not surprisingly, Loviisa was found in the top both in terms of data collection and predictive capability according to the mapping. Zabrze and Bytom on the other hand, were found least capable of predictive operations and data collection, which is also not surprising since these plants are two of the oldest of the units within Heat. For instance, old equipment does not have the same inherent adaptability to PdM technology, such as built-in sensors, as modern. In addition, according to the respondent representing these facilities production measurements are not used for maintenance purposes, which is one of the main reasons for the low score. Thus, this result with Loviisa in the top and Zabrze and Bytom in the bottom was expected and strengthens the quality of the mapping.

Modern plants such as Tartu, Järvenpää and Cz□stochowa were found more capable of predictive operations and measurements utilization than the general Fortum facility. Jelgava on the other hand, which was commissioned in 2013, was ranked lower than older facilities such as Suomenoja and Naantali. In other words, there is no definite correlation between commission year and predictive capability.

The results within Hydro are spread over quite a wide range. Hydro Finland is ranked considerably higher regarding predictive capability, while Hydro North Sweden is found at the top regarding use of measurements. This is the most surprising output of the questionnaire, since the cooperation within Fortum Hydro is regarded as much more developed compared to Heat. A closer analysis of the answers reveals that standards for PdM are defined in Finland and investigation of the potential for PdM has been conducted, as opposed to the Swedish regions. Also, production measurements are inserted automatically into Maximo in Finland. Hydro Finland and Hydro South Sweden stated that maintenance activities are based on analysis of historical production measurements and trends. Regarding the use of measurements, Hydro North Sweden utilizes all four concerned measurements, while the other regions only utilize two each.

Heat South and North West Sweden showed very similar results while Heat City scored slightly higher. The main reason that the Swedish plants within Heat are trailing the Finish plants is that no trend analysis for maintenance purposes of the most critical equipment is performed in Sweden. Furthermore, only vibration data is stored digitally.

4.1.2. Data collection capability

The degree of data collection capability served as an indicator for the potential of PdM and is based on a sample of measurements most commonly used for PdM. **Error! Reference source not found.** shows the overall percentage of utilization of measurements across all three divisions and units. As can be seen, all respondents utilize vibration analysis, which is one of the most common and widespread analysis methods for condition monitoring. Both lubrication oil analysis and infrared thermography are also widely used within Fortum, while only about a third of the stations utilize ultrasonic measurements. These results show that Fortum generally is utilizing the techniques identified as core technologies for PdM operations.

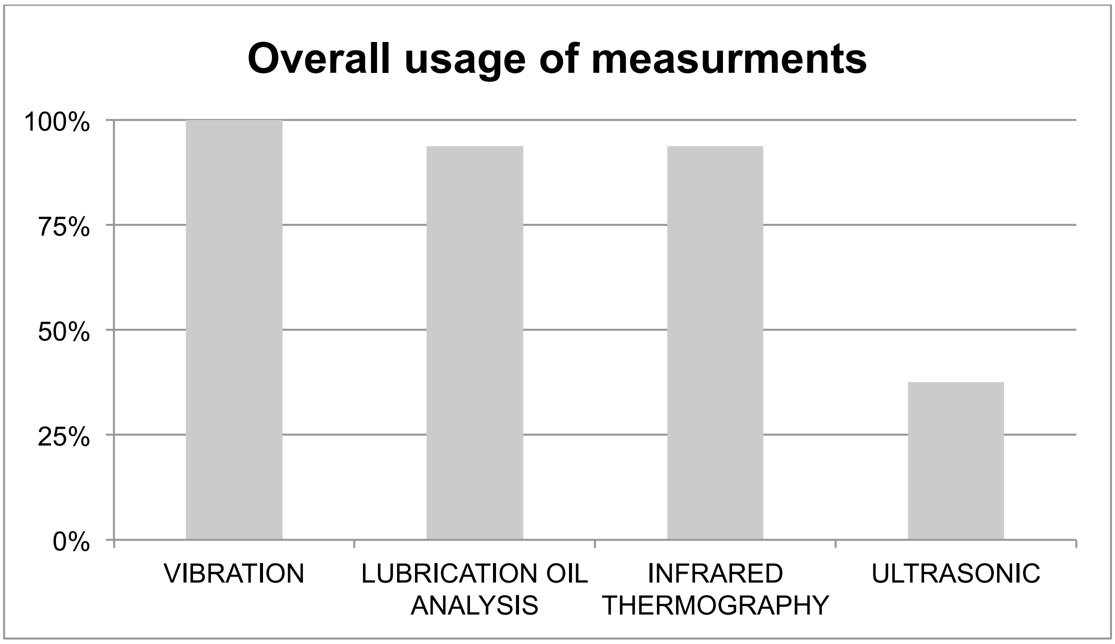

Figure 11: The use of four of the most common monitoring techniques in all of Fortum.

Figure 12 shows the use of the four measurement techniques presented for each division. At Loviisa, all techniques are used, while all units within Heat reported that vibration analysis, lubrication oil and infrared thermography are conducted and used for maintenance purposes, but ultrasonic measurements are utilized by almost a third of the plants. Vibration measurements are conducted throughout all three Hydro regions, while in only one of the three regions ultrasonic measurements are utilized and two out of three conducts lubrication oil, and infrared thermography analyses. Hydro North Sweden reported that all four measurements are performed, which explains the high score in terms of data collection capability.

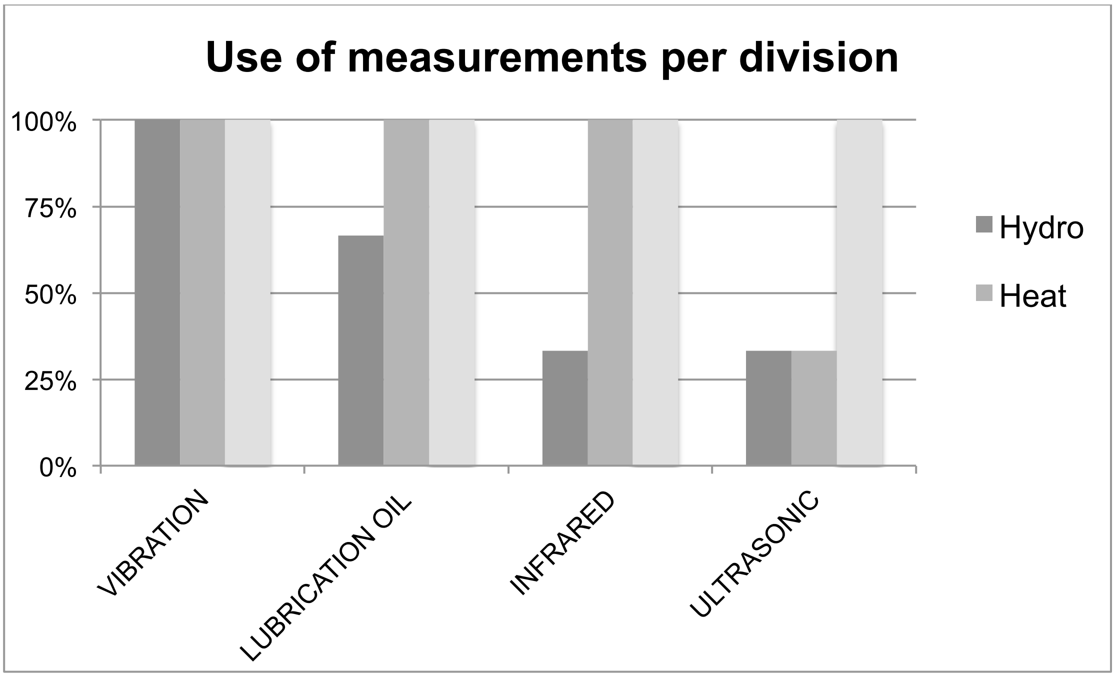

Figure 12: The use of monitoring techniques within each division.

The method for collection of measurement data is of interest for a number of reasons. First, collection of data manually is a risk due to the variation in the work process of individual operators leading to an uncertainty of cause for variations in results. Second, collecting data automatically is more efficient and enables online monitoring, which gives greater control of equipment condition. Hence, collecting data automatically is assumed to be beneficial for a PdM implementation. According to the questionnaire, the vast majority of the power stations collected the vibration measurements automatically while all other measurements were collected manually at all stations. It should be noted that no analysis of the cost justification of investment in automatic data collection for these types of measurements has been performed in this study. This question was included in the questionnaire with the purpose of assessing the current data collection capability and to identify any deviation in practices between the divisions.

PdM is based on trends analysis of data, therefore, it is of importance that data is stored digitally and accessible. Without any information about past operations, i.e. access to a historian database, no predictions of future performance can be made. So, it was of interest to investigate how the data storage processes functions at the plants. How the data is stored differs between both the different power units and the different measurement methods, see Figure 13. It ranges from being stored in a centralized or local database to not digitally or not at all. Here, a local database refers to a database that is only accessible from the concerned plant. It was considered to be most beneficial to have the data stored in a centralized database..

For vibration measurement and lubrication oil analyzes, around 50 % of the respondents answered that they do store the data in a centralized database. Regarding vibrations measurements, the remaining respondents stores data locally, while cases where data from lubrication oil analyses are not stored digitally exist. For the thermography the answers are almost evenly distributed between centralized storage, local storage and not digital storage. Data from ultrasonic measurements are most often stored non-digitally and never stored in a centralized database.

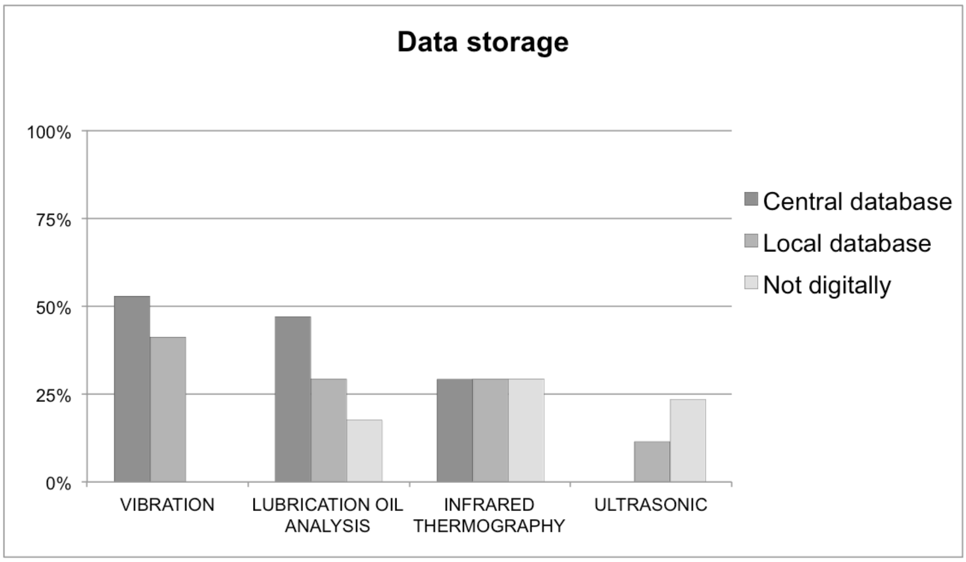

Figure 13: The storage of data for each measurement type.

At Loviisa data from all measurements besides the ultrasonic is stored in a centralized database for more than one year. Within Hydro, all data from lubrication oil measurements and thermography are stored in SharePoint. Vibration analysis is also stored in a centralized solution. Figure 14 shows the results from Heat. It can be seen that vibration data is in general stored digitally, while the storage method differs for the other techniques. These results show that there are no standards in place for how production measurements should be stored.

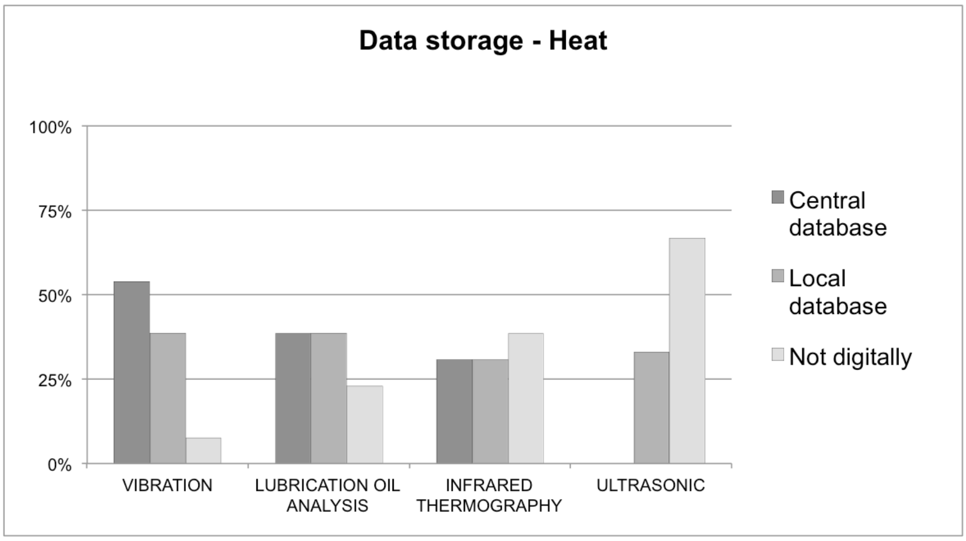

Figure 14: The storage of data within Heat for each type of measurement

4.1.3. Predictive capability

The maturity in terms of predictive capability was indicated by how the results of production measurements were used for maintenance purposes. Trend analysis is a cornerstone of a PdM program. According to the questionnaire, the use of trends differs between the divisions as Loviisa and all three Hydro regions perform trend analysis while the response differs within Heat. Overall, 70 % of the units reported that online-monitoring and trend analysis were used for the most critical components. It is assumed that the major maintenance investments are focused on the most critical equipment, thus this question reveals the most "advanced" maintenance type at each facility. Moreover, PdM efforts should be based on a criticality assessment, only one respondent answered that this was not considered for maintenance purposes.

Furthermore, previous investigations of PdM potential and standards for PdM were also taken into account when assessing the predictive capability. Whether standard work procedures for PdM exist in the facilities indicates how far a company has reached in its maintenance development. In total 60% of the facilities do have a standard for PdM implemented. Only one of the Hydro regions (Hydro Finland) currently had standards for PdM in place. Standards were in place at Loviisa and at all units within Heat Finland and Sweden.

Furthermore, 70% of the respondents answered that an investigation of the potential for PdM had been conducted a prior to this study. However, it should be noted that some respondents answered that no investigation of the potential for PdM had been performed but that standards were in place. These rather ambiguous answers might indicate that there can be differences in the perception of the concept of PdM and what a standard PdM work process is.

4.2. Qlikview

Fortum's Qlikview tool "Maintenance analyze", which allows for analysis of relevant KPI:s based on production measurements from Maximo, was used to further evaluate the current maintenance maturity of each plant. Figure 15 shows the percentage of PM-type (preventive maintenance) of the total number of work orders. This is a KPI that is commonly used to give an indication of how reactive the maintenance operations are at each production plant. The total number of WO:s includes the following types as defined by Fortum's Maximo work order hierarchy:

- Preventive maintenance (work order type 220)
- Condition based maintenance (work order type 230)
- Immediate repair (work order type 310)
- Deferred repair (work order type 320)

The work order types of the 300-series are considered corrective maintenance while the 200-serie is considered preventive maintenance. Data from the period of 2012-2014 has been used, however data was only available for 2013-2014 for Klaipeda and for Jelgava information could only be obtained from 2014. Furthermore, no work order information was found for Järvänpää and Tartu.

The green bars represents the production units within Heat, the blue bars represents the units within Hydro and the red bar represents Nuclear. Since Loviisa uses a separate version of Maximo, no data could be obtained from Qlikview, the value shown in Figure 15 is based on the interview conducted as part of the CNA-analysis. According to the Maximo data, the average percentage of PM-type work orders with in heat was 40 %. Pärnu and Klaipeda stands out with 60-70% preventive maintenance that is above the Fortum total average of 65 %. On the other hand, Jelgava and Heat South are the worst performers with less than 30 % preventive maintenance. All three Hydro divisions show very similar values with an average of roughly 85 % - considerably higher than the average within Heat. However, it should be noted that the value for Heat South did not correspond with the value reported by the maintenance manager during the CNA-analysis, whom reported that the actual value is roughly 50-60 %. This indicates that the accuracy in the Maximo data is highly depending on the actual use of Maximo, which may differ with location.

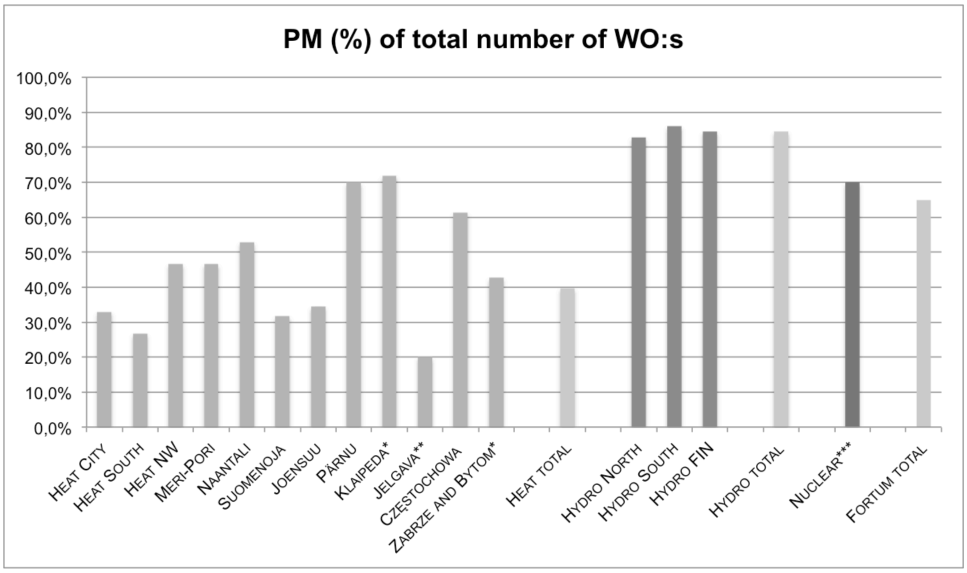

Figure 15: The number of preventive maintenance work orders of the total work orders for each plant based on Qlikview data from 2012-2014 (*Based on Qlikview data from 2013-2014, **Based on Qlikview data from 2014, * Based on interviews.)**

4.3. Benchmarking results

As described in section 3.5, it was decided to perform the Client Need Analysis (CNA) at the Loviisa nuclear power plant, Heat South Sweden and Krångede, representing Hydro South Sweden. In this section, the separate presentations of each CNA are followed by a comparison of the results for each division. By further investigating the current status and potential at these three plants, each representing a separate division and segment of the maturity grid, a wider picture of the potential for PdM at Fortum could be obtained.

4.3.1. CNA Nuclear - Loviisa

The results from the CNA at Loviisa are presented in the spider chart in Figure 16. A detailed discussion of the strengths and potential for improvement within each category is presented below.

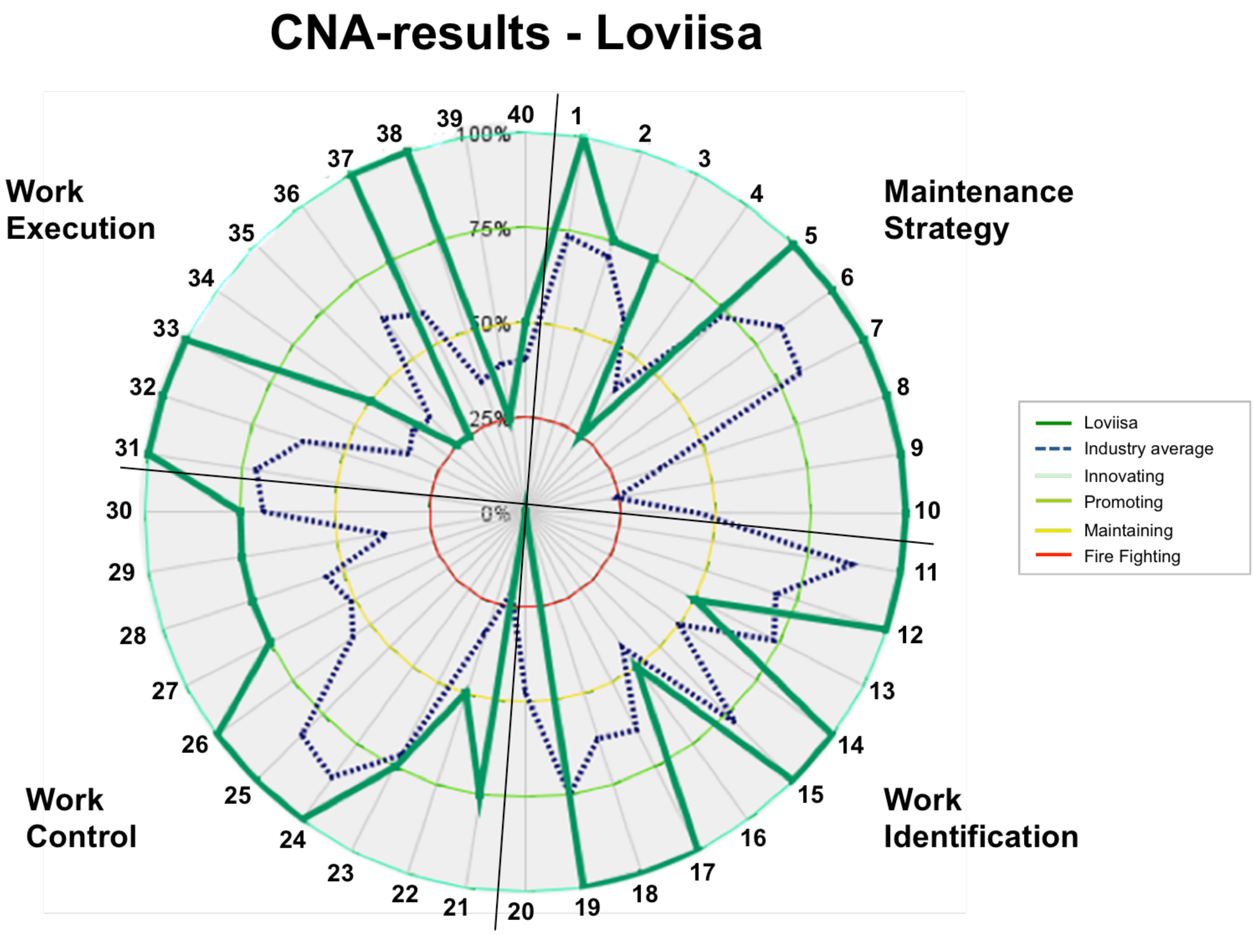

Figure 16: The CNA-results from Loviisa.

4.3.1.1. Maintenance strategy

Strengths:

The analysis shows that a well-defined and properly executed strategy is Loviisa's prime strength - over 50 % of the questions regarding strategy are in line with best practice. More than 80 % of all maintenance work is planned work, which shows that need for reactive actions is low and indicates a high level of maturity of the maintenance organization. Furthermore, over 80 % of all planned work is derived from standardized technical processes. The maintenance budget is only 1 % of the Estimated Replacement Value (ERV) - best practice is considered less than 2.5 %. This indicates effective maintenance operations with low need for expensive reactive actions.

Virtually all equipment at Loviisa has been subject to a criticality analysis that is derived from American standards for criticality. All components have class 1-4 based on production and safety criterions. This is a key factor for a successful CBM program since the predictive actions should be focused on the most critical equipment in order to be effective.

The asset register is detailed and up-to-date which is a requirement for work order control and monitoring of relevant KPI:s. Loviisa also scores high in terms of analysis of previous malfunctions and failures, which was expected due to the high safety regulations related to production of nuclear power. Between 80-100 % of all significant events are subject to a structured root cause failure analysis.

Potential for improvement:

Regarding strategy, Loviisa is only below the industry average on one account, which is the inventory cost (the value of spare parts in relation to ERV.) However, this parameter is generally high for the power industry, which can be seen in the chart (question number 4) since the industrial average is below the “Maintaining” level.

With an overall availability of roughly 93 %, Loviisa is above the industry average but below the best practitioners, which lies above 95 %.

4.3.1.2. Work identification

Strengths:

Practically all maintenance work performed at Loviisa is linked to a written and documented work order and more than 60 % of the work orders are planned based on a well-defined process that contains origination, authorization, technical necessity, and budget. A priority system based on predefined criterions is in place through which all work orders passes

A well-established CBM program is in place. All recommended actions as output of the CBM program are subject to an established decision support process a prior to implementation. A highly structured change management process is also in place through which all changes and improvements needs to pass.

Potential for improvement:

Currently, the operators are tasked with a rather low higher share of the preventive maintenance work. The PM actions performed by the operators could be increased, since a shared responsibility for the PM program between maintenance and operators is considered best practice.

At present, there are no detailed information regarding the required skill-set are included in the work order information. More thorough information is desired since this increases the probability of the right person performing the right task correctly. Furthermore, the number of work order types could be decreased to improve clarity. The recommended number is 5-7, Loviisa currently has more than 8 types.

4.3.1.3. Work control

Strengths:

Both PM and CBM schedule compliance, which are also used as standard KPI:s, are more than 70 %, which is considered best practice. The budget compliance is less than +/- 2 % and also in line with best practices.

Potential for improvement:

The average deviation of estimated versus actual job times, which is a standard KPI at Loviisa, is +/- 5 %. Best practice is considered +/- 2 %. Note, however, that the industry average is even higher with +/- 25 %. The level of overtime versus total work time is also higher than for best practitioners. Also, the number of planners in relation to craftsmen is considered to be at the "Maintaining" level. These results indicate room for improvement in terms of work planning and scheduling.

To increase work efficiency, additional Standard Job Plans (SJP) that includes scope, required craft and skill-level, technical information etc. could be developed to include the work types that are not currently covered by standard procedures. In the best practice case, over 80 % are standard jobs, Loviisa are currently only covering about 70 % of the known work with standards. Moreover, the percentage of equipment that has an accurate Bill of Material (BoM) could also be improved in order to increase inventory and spare-parts control.

4.3.1.4. Work execution

Strengths:

Detailed work order history is logged and recorded in Maximo for more than 80 % of the total work orders and the effective work time of the maintenance personal is roughly 70 %, which is to be compared with 50 % for the best practitioners. Standards for testing and control of maintenance actions are well established and covers roughly 90 % of all planned work. Furthermore, the percentage of rework is in line with best practice, which indicates a highly effective maintenance organization.

Potential for improvement:

At present, less than 50 % of the performed corrective maintenance activities are subjected to a review that evaluates the actions and focuses on loss, cause and cost effective solutions. Likewise, only about 50 % of the PM and CBM actions are followed up by a review. The current training hours per maintenance craft men corresponds to the ”Maintaining” level. However, this is still above the industry average.

4.3.1.5. Summary

Overall, the maintenance organization at Loviisa is considered to be a top-class performer. The results are almost exclusively above the industry average and in general well in line with best practices. Listed below are the key takeaways from the CNA-results at Loviisa:

- The main strength is a well-defined and properly executed maintenance strategy, which includes a standardized criticality assessment, an accurate and updated assets register and an extensive RCFA process
- A CBM program is in place and the recommendations are subjected to a structured decisions support system a prior to implementation and all improvements passes through a predefined change management process
- The main areas of improvement concern the organizational structure of planners and craftsmen, decreasing the cost of inventory and further developing the standard job plans

4.3.2. CNA Heat – Heat South Sweden

The results from the CNA at Heat South are presented in the spider chart in Figure 17. A detailed discussion of the strengths and potential for improvement within each category is presented below.

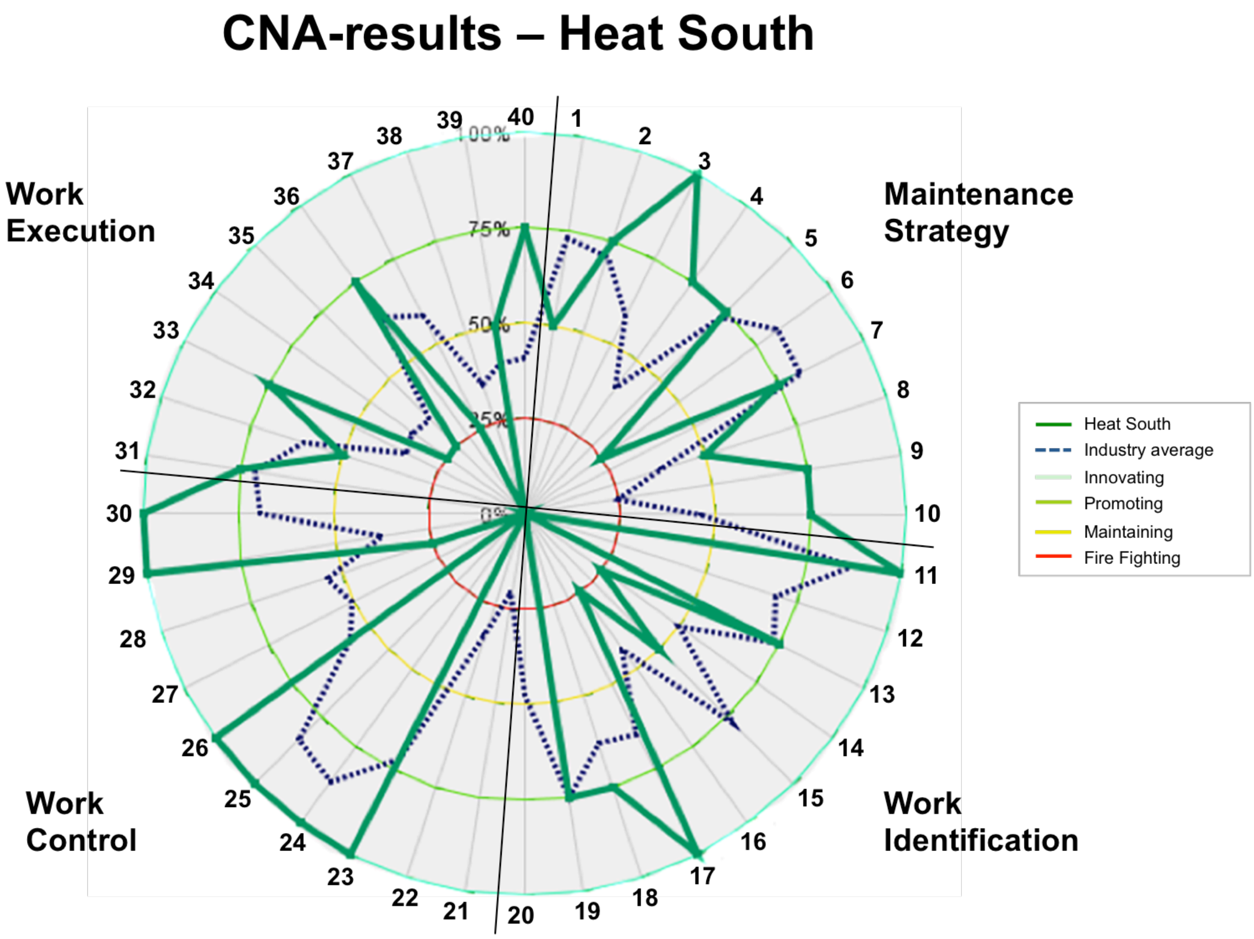

Figure 17: The CNA-results of Heat South Sweden.

4.3.2.1. Maintenance strategy

Strengths:

The level of availability is roughly 90 %, which is slightly above the industrial average and the ratio of planned versus unplanned maintenance indicates a fairly low level of reactivity. The maintenance cost is in relation to sales in line with best practice, but the annual maintenance budget is roughly 3.5 % of the ERV, which is higher than the industrial average. However, it should be noted that this KPI is a rough indication since the concerned industry segment includes several different types of facilities. To obtain an accurate benchmark of the actual maintenance cost a comparison with similar types of power producing facilities needs to be conducted.

RCFA is performed for roughly 70 % of all significant events, which is well above the industrial average. However, best practitioners cover more than 80 %.

Potential for improvement:

According to the chart, Heat South is at a “promoting” level in terms of maintenance strategy (question 9 focuses on strategy separately). However, it should be noted that RCM and FMEA are used at Loviisa, while in the case of Heat South the vast part of these assessments rely on experience rather than a pre-defined technical process. Likewise, the criticality analysis is based on experience and covers only about 50 % of the plant equipment. In the best practice case, a standardized criticality assessment is performed and includes more than 80 % of the equipment.

The current depth of the assets register is in line with the industry average, but it is only up-to-date and covering 25 % of the equipment, which is well below the industrial average. A well maintained assets register is an important platform for the use of relevant KPI:s.

4.3.2.2. Work identification

Strengths:

Basically all work orders are documented and linked to a written work order, the different work order types are clearly defined and all WO:s passes through a pre-defined priority system. The majority of the improvements and changes are also subject to a change management process. A thorough CBM program including well-defined routes and periodic measurements is in place.

Potential improvements:

There are ongoing efforts to develop the online monitoring scheme, which is an important platform for moving towards a more PdM approach. Currently, there is software in place with the capability of online monitoring of rotating machinery, but the processes for analyzing this data can be improved.

Furthermore, the level of detail included in the work order information in Maximo concerning the required skill to perform the task can be developed. However, it should be noted that the maintenance managers are aware of this fact but currently; this is not considered a high-priority issue.

4.3.2.3. Work control

Strengths:

With a scheduling horizon of over 4 weeks, a backlog of less than 3 weeks, and an average of 5 % overtime versus total job time, Heat South is well aligned with best practice. The budget compliance and the compliance of the preventive maintenance schedule also correspond to best practice. These factors all indicate a high capability of planning and schedule compliance.

Potential for improvements:

Currently, the average deviation of estimated versus actual job times is not measured. This is an important KPI for further monitoring the schedule compliance. Also, there are no Bills of Material that registers stock items, locations, order quantities etc. This is an important tool for controlling the stock to make sure that necessary components are in place when needed. Currently, a process for controlling the inventory is established, but a connection between assets’ need for spare parts and location could be developed.

At present, there are standard job plans for less than 10 % of the total known work that is performed. Best practice is considered to be more than 80 % standard jobs. This indicates a lack of structure and organization for getting known work done effectively and properly. It should be noted that this is also a fact that the maintenance managers at Heat South are aware of but do not consider this necessary to develop at this time.

4.3.2.4. Work execution

Strengths:

Between 60-80 % of all work orders are closed with a fairly detailed history recorded. According to a previous investigation conducted in 2013, the effective work time in relation to total work time of maintenance labor is roughly 45 %, which is well above the industry standard. Follow up and diagnostics of roughly 75 % of the total number of PM tasks is performed, which corresponds to the “Promoting” level.

Potential for improvement:

Educational efforts are conducted and training schemes are developed for the craftsmen. According to the results, the number of training hours could be increased. However, it should be noted that this question is somewhat hard to judge since the amount of training required might differ depending on what improvements and changes are made at the concerned facility. The response in this case refers to the amount of ongoing training hours focused on competency improvements of the craftsmen.

Moreover, there are currently no standards for testing and controlling of performed work tasks and the need for maintenance rework is not measured.

4.3.2.5. Summary

Overall, the maintenance organization at Heat South is above the industry average and considered to be at the "Promoting" level. The main strengths are related to work control while the main weakness concerns the work execution and maintenance strategy and the current level of proactivity is fairly high. The following are the key takeaways from the CNA at Heat South:

The PM program and budget compliance, the scheduling horizon and the backlog are in line with best practice. This indicates a high capability of accurate planning and fulfillment of maintenance tasks

- The current status of the assets register is considered to be at the "Fire Fighting" level according to the CNA-results. However, it should be highlighted that the current register includes locations and equipment etc., but the structure of the register could be developed to facilitate the use of relevant KPI:s for measuring the performance of the maintenance unit.
- The current criticality assessment could be extended and improved by using a standardized method. This facilitates the development of a PdM program since a cost effective program should be focused on the most critical equipment.
- Currently, there is a well-structured CBM scheme in place including routes and periodic measurements but the process of using data from continuous online monitoring for maintenance purpose could be further developed.

4.3.3. CNA Hydro - Krångede (Hydro North Sweden)

The results from the CNA at Krångede are presented in the spider chart in Figure 18. A detailed discussion of the strengths and potential for improvement within each category is presented below.

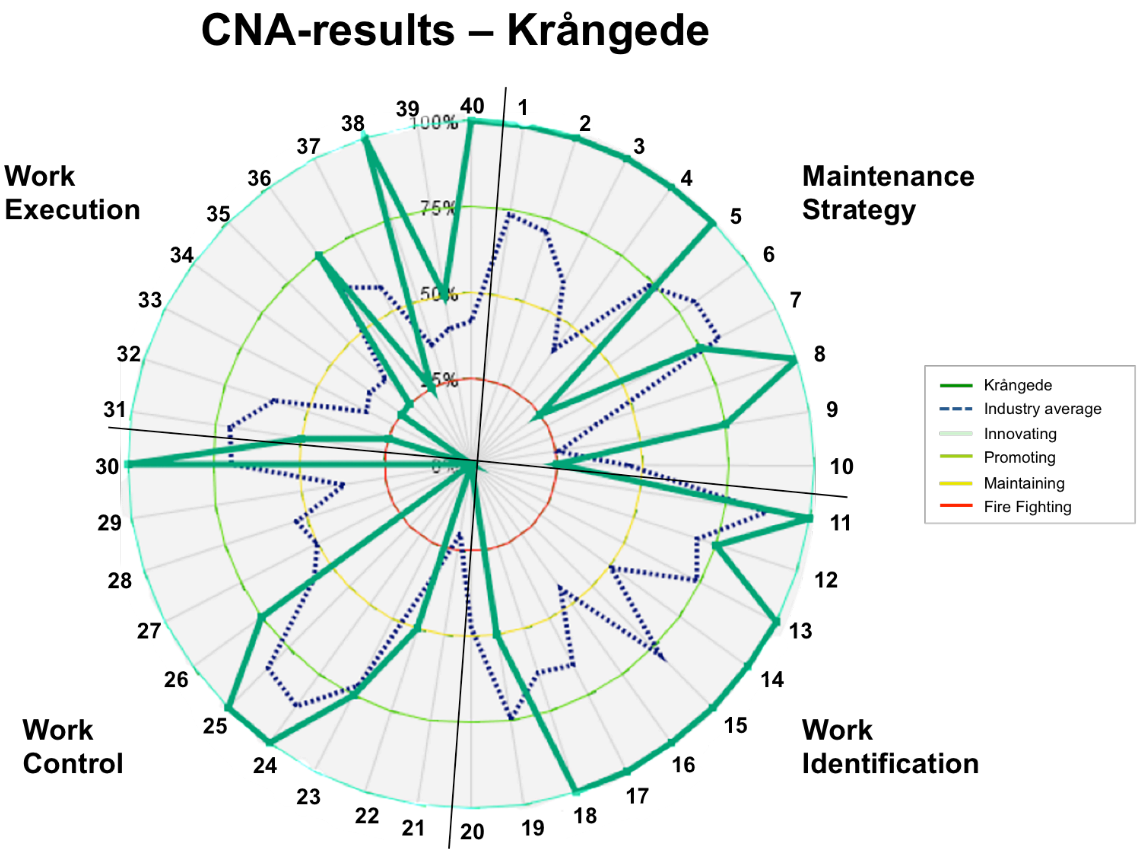

Figure 18: CNA-results of Krångede that represents Hydro North Sweden.

4.3.3.1. Maintenance strategy

Strengths:

Krångede is in line with best practices in terms of all cost performance indicators, which include maintenance cost in relation to ERV, maintenance cost versus total sales turn over and inventory value. Also, the level of availability is roughly 95 %, which is considered best practice. These factors indicate a cost efficient and effective maintenance organization.

More than 80 % of the equipment has been subjected to a structured criticality assessment, which is in line with best practice and well above the industry average of less than 40%. Furthermore, 61-80 % of all planned work is derived form a standardized technical process, for example FMEA and RCM, which is considered to be the "Promoting" level. The ratio of planned versus unplanned maintenance is estimated to 88 % which is also considered best practice. These parameters all indicate a high level of proactivity.

Potential for improvements:

In terms of maintenance strategy the assets register is the main weakness at Krångede. Less than 50 % of all equipment is estimated to be included in an accurate and updated register, which is to be compared with an industry average of between 61-80 % and a best practice of more than 80 %. An update assets registers is a key factor in order to establish an effective process for measuring of relevant KPI:s. Moreover, the follow up of failures could be improved. Currently, less than 40 % of the significant events are subject to a RCFA, which is considered to be at "Fire Fighting"- level.

4.3.3.2. Work identification

Strengths:

According to the CNA, work identification is the main strength at Krångede. Virtually all recommendations that are based on the PdM program are subjected to a decision support process before implementation. A structured change management process is also in place, which covers basically all changes and improvements. Since the maintenance operations are outsourced all tasks are initiated by work orders and passes through a priority system.

However, it should be noted that the questions regarding operator care are not fully applicable in this case. At the hydropower facilities the on-site staff is responsible for both operations and maintenance tasks, which results in very high levels of operator care.

Potential for improvement:

The accuracy of the recommendations as a result of the CBM program is at estimated to be between 61-80 %. This is above the industrial average but best practice is above 80 %. Currently, there is no information regarding what exact skills are required for the task included in the work order information. However, it should be noted that the maintenance manager does not consider this necessary.

4.3.3.3. Work control

Strengths:

The schedule compliance of the PM and the CBM programs are in line with best practice, while the budget compliance, the ratio of planners to craftsmen and the scheduling horizon are considered to be at the "Promoting" level. These factors indicate a fairly good ability to plan and fulfill scheduled work tasks.

Potential for improvements:

The average deviation of projected versus actual job time is not currently being measured and there are presently no definitions of standard jobs. Also, since the maintenance operations are outsourced, the maintenance manager at Fortum has currently no knowledge of the backlog. The lack of information explains the low scores indicated by the spider chart. Furthermore, the equipment that has an accurate BoM is less than 10 %, which is considered "Fire fighting" level

4.3.3.4. Work execution

Strengths:

There is a structured process for assessing the frequencies, work content, check lists etc. that are included in the PM/CBM programs. Between 81-100 % of all planned PM and CBM activities are subjected to a review focused on these and additional factors.

Potential for improvements:

Work execution is the Krångede's weakness of the four areas according to the CNA-result. Less than 4 % of the total work is estimated to be rework, but no actual numbers are available since this value is not measured. There are no standard practice for control and testing of performed maintenance tasks. Furthermore, work order history only covers between 40-60 % of all work orders and this history dose not include details such as labor cost, material costs and actual versus estimated job time. At present, there are no numbers that shows "wrench time", which indicates the level of actual hands-on work time in relation to the total job time.

4.3.3.5. Summary

The CNA-results shows that Krångede is above the industrial average and fairly well aligned with best practices. Cost effectiveness and work identification are the main strengths, while the work execution shows room for improvement. The key takeaways are listed below:

- A lack of data shows that there is currently a lack of transparency between Fortum and the outsourcing partner
- A thorough criticality assessment and a well-defined maintenance strategy are in place. The compliance of the existing CBM program is top class but the accuracy of the findings can be improved
- The present status of the assets register is considered to be at the "Fire fighting" level and the follow up of work orders could be improved - the current process for work order history could be developed and the use of RCA of to analyze significant events could be extended

4.3.4. Comparison of the CNA-results

As can be seen in the spider charts, the general score is above the industrial standard at all three facilities. Table 2 through 4 shows the "Summary Matrix", which summarizes the scores in each category for each of the facilities. Looking at the subtotals it is clear that Loviisa is the top performer with 55 % of the answers in line with best practice. 45 % of the answers at from Krångede were considered to be at the "Innovating" level and the corresponding number was 22.5 % for Heat South Sweden. Looking at the "Fire Fighting" column, it can be seen that Heat South Sweden also had that most answers at this level. Furthermore, the absent column indicates to what extent data was missing or not applicable. 12.5 % of the questions were unanswered at Krångede, which were mainly due to a lack of transparency between Fortum and the outsourcing partner. Listed below are the common strengths and potential improvements for the three facilities.

Common strengths:

- Generally very strong within “Maintenance strategy”, all three above industry average on the majority of the questions.
- Strong PM programs, consistently derived from structured processes.
    - High planned vs. unplanned is an indicator of well-developed PM programs.
- Exceptionally good schedule compliance of PM and CBM, all three facilities are “Innovating”.
- Criticality assessments are utilized throughout the facilities. Though, the type of methods for these assessments differs.
- WO are generally used, and passed through priority systems. However, lacking detailed information.

Common improvement potential:

- Maintenance execution the weakest area of the four.
    - Education, supervisor/craftsman ratio, review of corrective actions is all low.
- Heat South and Krångede have undeveloped asset registers.
- Operator compliance of maintenance tasks are lower than industry average on both Heat South and Loviisa, not applicable for Krångede.
- Complimentary information on WO:s generally low.

A mentioned, Loviisa is the top-performer compared with the two other facilities according to this benchmark. However, all three facilities show different peak strengths and improvement potential. Loviisa uses relevant KPI’s, along with good control over the work processes for instance through structured processes for criticality analysis and change management. The CNA show that Heat South Sweden has high capability of planning and schedule compliance, indicating a strong preventive maintenance program. There is however a lack of control of the maintenance organization, for instance by utilization of KIP’s. Finally, Krångede are according to the CNA very strong in cost performance and in proactive measures such as criticality assessments and RCA. The newly outsourced maintenance operations is however affecting the comprehensive view of the maintenance organization, for instance the backlog and planning horizon.

Table 2: Summary of the CNA-results at Loviisa.

Main facet / maturity	Absent	Fire fighting	Maintaining	Promoting	Innovating	Not applicable	Not understood	Totals facet
Maintenance strategy	0.0	2.5	0.0	5.0	17.5	0.0	0.0	25.0
Work identification	2.5	0.0	5.0	0.0	17.5	0.0	0.0	25.0
Work control	0.0	0.0	2.5	15.0	7.5	0.0	0.0	25.0
Work execution	0.0	7.5	5.0	0.0	12.5	0.0	0.0	25.0
Subtotals per choice of response	2.5	10.0	12.5	20.0	55.0	0.0	0.0	100.0

Table 3: Summary of the CNA-results at Heat South Sweden.

Main facet / maturity	Absent	Fire fighting	Maintaining	Promoting	Innovating	Not applicable	Not understood	Totals facet
Maintenance strategy	0.0	2.5	5.0	15.0	2.5	0.0	0.0	25.0
Work identification	0.0	5.0	2.5	7.5	5.0	5.0	0.0	25.0
Work control	5.0	2.5	0.0	0.0	15.0	2.5	0.0	25.0
Work execution	2.5	7.5	5.0	10.0	0.0	0.0	0.0	25.0
Subtotals per choice of response	7.5	17.5	12.5	32.5	22.5	7.5	0.0	100.0

Table 4: Summary of the CNA-results at Krångede.

Main facet / maturity	Absent	Fire fighting	Maintaining	Promoting	Innovating	Not applicable	Not understood	Totals facet
Maintenance strategy	0.0	5.0	0.0	5.0	15.0	0.0	0.0	25.0
Work identification	0.0	0.0	2.5	2.5	17.5	2.5	0.0	25.0
Work control	10.0	0.0	2.5	5.0	7.5	0.0	0.0	25.0
Work execution	2.5	10.0	5.0	2.5	5.0	0.0	0.0	25.0
Subtotals per choice of response	12.5	15.0	10.0	15.0	45.0	2.5	0.0	100.0

4.4. Key takeaways from internal case studies

The most important findings based on the study of archived documents, covering previous projects focused on PdM, and on interviews conducted as a part of the CNA-analysis are presented below.

4.4.1. Benefits of PdM has been shown

Benefits in terms of increased up-times and avoided failure by using PDS solutions were shown during a test pilot in Suomenoja. However, no further actions to implement this type of software at Fortum have been conducted since 2012 because the economical benefits could not be clearly illustrated. The benefits of PdM in general can also be seen according to the pre-study of vibration technologies in Heat South, but there is a need for clearly identified KPI:s in order to measure the economical performance of the investments in condition based and PdM. However, the asset register is in general not “deep” enough to allow the required follow up of relevant KPI:s. Efforts to create a common platform for identification of components, which is required for building a detailed asset register, have been conducted but the systems used differ between and within the divisions. The Qlikview application is supposed to function as a tool for monitoring important maintenance and operations KPI:s, but there is no standard for how this tool is to be used by the maintenance units. At present, a general skepticism of the accuracy of the Maximo data exists within the organization but the level of usage and trust for the application is on the rise.

4.4.2. Power Solutions are mainly focused on Heat Finland

Power Solutions, as an internal consultant agency in the area of improvement work within the power industry, has extensive experience regarding condition monitoring and trends analysis. The questionnaire showed that that 53% of the respondents have had current or previous cooperation with Power Solutions. At present, there is no or little cooperation with Hydro. Moreover, it is interesting to note that previous projects performed within Heat South were deemed unsuccessful because the output from trend analysis could not create any value since there were more critical issues to deal with. On the other hand, all Finnish production units apart from Järväänpä have ongoing projects or previous experience from working with Power Solutions. This indicates that the level of maintenance maturity differs between the regions.

4.4.3. The coordination of PdM projects can be improved

There is a lack of coordination of PdM projects and several plants have developed local stand-alone solutions. The kind of software also differs from ordinary data handling software such as Excel to dedicated condition monitoring software. These differences expose that there is no holistic consistency regarding software usage within Fortum. Especially within Heat, the software used for vibration monitoring etc. differs locally and several contractor that provides similar services are used in the same regions. However, projects aiming to consolidate the PI-systems within Heat are conducted. Furthermore, as an attempt to increase the automation of data collection, a mobile Maximo solution has been developed. However, this project is questioned by the maintenance personal and the use of the application is limited.

4.4.4. Compliance with work processes differs between regions

Standard work processes for carrying out maintenance activities and for scheduling future maintenance actions are in place within Fortum. However, the compliance with these processes differs between the units and the divisions as the usage of Maximo differs with locations as adaptions of the standard processes are made locally. According to the questionnaire, 25 % of the units do not report manual production measurements to Maximo, which further highlights the fact that Maximo is used differently across the organization.

4.4.5. There are no common standards for PdM in place

Although solutions for collection required data to produce trends are in place, there are no current standards in place that defines how this information should be analyzed and used to schedule and improve maintenance activities. Furthermore, there is no clear organizational structure of roles and division of responsibilities for the predictive work. Since performance monitoring is closely linked to PdM the cooperation between the maintenance and operations units can be improved. Experience from Power Solutions as well as the results of previous PdM and condition monitoring projects points at the benefits of using a “Performance Center”-business model for analysis of trends and production data. This refers to the model with a centralized unit that analyzes data from several power plants using a set of digital solutions that might include performance monitoring software, PDS systems and additional stand-alone solutions.

To summarize, based on the internal case studies the following key takeaways were identified:

- Benefits of PdM can be seen but investments cannot be justified, mainly due to lack of relevant KPI:s
- PdM initiatives are currently taken, but the coordination of these projects within and between different regions can be improved
- PDS solutions has been investigated within Fortum and the technique has been deemed successful but no economical justification has been clearly shown
- Fortum's internal consultant agency Power Solutions has great expertise in the area of condition monitoring and PdM but their services are mainly used at plants within Heat Finland
- Compliance with current standard work processes differs between regions and can be improved
- Standard work processes for PdM actions are not in place and needs to be developed in order to create successful PdM programs

4.5. Key takeaways from external case-studies

In addition to the case studies of previous projects at Fortum, a review of PdM related projects performed at other companies was conducted based on material provided by contact persons at Fortum. Also, the ARC Advisory Group provided a summary report of a survey focused on PdM conducted in 2014, which included responses from 150 maintenance managers mainly operating in the States.

4.5.1. Centralized monitoring is the preferred business model

Examples of PdM programs within the power industry also highlights the benefits of a central Performance Center, which goes well in line with the takeaways from the internal case studies. Furthermore, it is interesting to note that the cases found when PDS solutions have been deemed unsuccessful are cases when the systems have been used locally at a specific plant. The main reason that motivates the use of centralized monitoring units is the high level of expertise needed for deploying, analyzing and maintaining the PDS models. Furthermore, synergy effects of building models based on data from several different plants can be seen.

4.5.2. Cost justification by conducting pilots

To find models for justification of the full-scale PdM programs is difficult, but many success stories of previous implementation can be seen. The mainstream view of how a successful PdM program should be established include conducting pilot tests at certain facilities or to start with stand-alone solutions and further develop the scope of the program once the benefits can be shown.

4.5.3. Investments in PDS solutions on the agenda

According to the survey conducted by ARC, traditional PdM techniques are widespread while PDS solutions are rare. However, PDS are considered a valuable tool and investments in these types of systems are on the agenda for 30 % of the respondents. Main obstacles to further investments in PdM initiatives are budget constrains and undefined benefits. The use of KPI:s for measuring avoided downtime is considered the best way to increase the understanding of the effects of PdM.

5. Discussion

In this chapter, the findings, the analyses and the methods used in this project are discussed. Further, uncertainties related to the research are brought up for discussion to justify and explain the underlying arguments to the final conclusions.

5.1. Results discussion

In this section, the results produced in this project are analyzed and discussed.

5.1.1. Discussion of the situation analysis

As Diamond & Marfatia (2013) notes, in order to successfully implement PdM, lower-level maintenance types are needed to be in place. In addition, Moubray (1997) highlights that an organizational structure is of great importance as well. Thus, the situation analysis served as a base for the evaluation of Fortum's potential for a PdM implementation. The main aim of the situation analysis was for it to serve as an indicator of the level of maintenance maturity of the concerned plants. However, the questionnaire gave a number of interesting results, which are discussed in this section.

5.1.1.1. Loviisa – a front-runner

Mobley (2002) cites that effective decision-making procedures are of importance for a PdM program. Furthermore, a number of steps are according to Groba et al (2007) and EPRIGEN (1998) important for a successful PdM implementation, including a strong decision-support system and an organizational structure. In this thesis, documents considering development of change management processes at the Loviisa plant were found, which indicated a well-developed organizational structure. Furthermore, the strict regulations and safety directions within the nuclear industry were pointed out as a key factor to the amount of production measurements used. Particularly because increased control has resulted in progress within areas related to PdM, such as condition monitoring and predictive analytics. As mentioned above, Diamond & Marfatia (2013) writes that PM and CBM are needed to be in place for a successful PdM program. It was disclosed through interviews with Loviisa personnel that development of CBM and PdM has been in progress for over 20 years at the nuclear power plant, which adds to the perception of Loviisa as a front-runner regarding an implementation of PdM.

5.1.1.2. Data collection capability

The four measurement methods of concern in this study are four of the most commonly used PdM techniques, utilized to predict equipment failure (US Department of Energy 2010). This served as support for the assumption that by investigating the usage of these four techniques would add to an indication of how the mindset is at Fortum regarding PdM. If no measurements are conducted, it indicates that there is an extensive development process for Fortum before PdM can be implemented. If however all four measurements are conducted, it implies that the organization is more capable. The capability is partly due to the need for investments, which is reduced if PdM techniques already are utilized. Partly, it indicates that the facility is having a predictive mindset, since the techniques involves trying to analyze the physical condition of an asset in order to predict failure.

Generally, the data collection capability is considered good at Fortum, with the majority of the facilities utilizing the majority of the concerned measurements. This in turn would imply that competencies and investments for data gathering, handling and analyses already are in place. So, barriers such as initial investments and education should be lesser of a problem. It is however not clear how, and to what degree, the data is gathered and used for e.g. trend analyses, but it can be concluded that the methods vary greatly. Therefore, the adaptability to PdM is assumed to vary as well.

Vibration analysis is considered the foundation of PdM and is highly useful in predictive purposes (US Department of Energy 2010). It is also highly compatible with digital solutions, which makes it an appealing technology (Mobley 2002). Vibration techniques are according to this project utilized throughout Fortum, which is a good indicator of PdM capabilities. As mentioned above, it is however unclear to what degree the measurements are used within maintenance. Projects regarding this have already been conducted within Fortum, which was highlighted the section 4.5 Key takeaways from internal case studies. Such projects are indicators that Fortum is moving towards the PdM area. However, a separation within the organization is clear. The internal case studies showed that experiences and lessons learned on some plants through local projects are often not transferred to other parts of the organization.

5.1.1.3. Criticality and trends analysis

Criticality assessments are according to Gomez de Leon Hijes & Cartagena (2006) foundational for a successful maintenance program. Additional organizational structures, such as functioning change management and priority system is also identified as important. The lack of such processes at Zabrze and Bytom indicates that the maintenance maturity is far below the average Fortum plant, and that the differences to the top-performer Loviisa are significant. It was seen in the situation analysis that even though the majority of the facilities were not utilizing trend analysis in general, 70% stated that for the critical equipment trend analysis is performed. This indicates that there is a general understanding that criticality assessments are of importance, which (Moubray 1997) emphasizes. Only one respondent stating that criticality is not considered. Whether the criticality assessments are performed from some sort of structured framework was however not investigated, but would be of interest. From other phases of the study it has been shown that the assessments of criticality differ throughout Fortum. Here, Loviisa is a good example of having a structured criticality assessment method, which is based in an American standard for criticality. On the other hand, some facilities base their criticality assessments on previous experience, which is harder to justify. Documents regarding standard criticality assessments has been seen in this study, the usage of these are however unknown.

Also, this result shows that the majority of the facilities do conduct some sort of PdM, at least for the most critical equipment. This is interesting as the majority of the respondents stated that they do not use production measurements for trend analyses in general. Thus it indicates that even though the general maintenance activities do not incorporate PdM activities, most of the plants have the capability to do so for the most critical component.

It should also be noted that the two Polish plants were acquired recently, in 2010, which can be a reason for why this response stands out. Common work processes and use of production measurements within the company might for instance still be in progress of implementation at Zabrze and Bytom.

5.1.1.4. Discussion of the differences within Heat

The situation analysis showed that the maintenance operations regarding use of production measurements vary rather widely within Heat. One of the top performers within Heat, Częstochowa, is found to incorporate a lot of maintenance practices in line with PdM. This includes for instance having structured decision-support and priority system in place (Mobley 2002). Further, Częstochowa stated that a defined standard work process for PdM is in place, and having previously investigated the potential of a PdM implementation, as opposed to Zabrze and Bytom. Also, trend analysis, which is a core activity of PdM according to Prajapati et al., (2012), is produced from the production measurements at Częstochowa. Regarding the Data collection capability, all four of the concerned PdM techniques are utilized along with beneficial handling of the data produced.

The large variation of answers within the Heat division could depend on the differences in level of technology within the plants. As the facilities ranges from being constructed in the 19th century up until this decade, the level of technology is known to vary. Also, the wide range of geographical locations is assumed to matter as well. It can be concluded that within the national regions, the differences are much smaller. An explanation for this can be the closer cooperation existent within the nations, due to cultural aspects and the ease of communication. The geographical differences are evident on a technical note as well, for instance with Heat Sweden having the IP21 system while the majority utilizes TOPi. Moreover, a major geographical difference is that Power Solutions are mainly operating within Finland and the rest of Europe, while not being as active within Sweden.

5.1.1.5. Discussion of the differences within Hydro

One of the most surprising observations of the situation analysis was the wide difference within hydro, especially regarding data collection capability. According to the interviews conducted with maintenance managers and spokes persons for both Hydro and Heat, the hydro division was considered more aligned in its maintenance organization than Heat. The deviating result is though mostly due to the differences in utilization of PdM techniques. The fact that the four techniques involved in the questionnaire merely is a sample, and is thought to be functioning as an indicator of how predictive the maintenance organizations work, one cannot draw too many conclusions regarding the diversity of the maintenance organizations within Hydro. Due to the few techniques involved in the questionnaire, the usage of one technique affects the outcome significantly. To achieve a precise picture of the data collecting capability at Hydro, a more thorough analysis would be needed.

What can be concluded, however, is that vibration analysis is conducted in all three Hydro regions as opposed to the other measurement techniques. This goes well in line with the view in theory that it is one of the most used technologies (US Department of

Energy 2010). In turn, it can be argued that vibration analysis can be the enabler of cooperation within the Hydro division.

An uncertainty regarding the result of Hydro is that the maintenance operations are recently outsourced. As many of the work processes therefore has changed, the research has been surrounded by a bit of ambiguity regarding the maintenance process, which has made some answer difficult to get.

5.1.1.6. Summary of the situation analysis discussion

In summary, the situation analysis shows that Fortum presently is facilitating several of the components needed for a PdM program. The first step of implementing such a program is the identification of significant equipment and indicators, performed through criticality analyses and failure mode analyses (Groba et al. 2007). Gomez de Leon Hijes & Cartagena (2006) claims that performing a structured criticality assessment is of importance. Whether the criticality assessments performed within Fortum are derived from some kind of structured framework was not investigated. Further research in this matter did however point to that both structured frameworks and self-developed experience-based methods exist within Fortum.

The next step of a PdM implementation is to measure the indicators. It could be seen in the results that all facilities are measuring at least some of the four traditional PdM techniques. The last steps of the implementation process presented by Groba et al (2007), modeling and forecasting of the indicators and developing effective decision-making procedures were not as detailed investigated. It was however indicated that some facilities did perform both modeling and forecasting of the indicators.

The majority of the facilities are utilizing several of the traditional PdM techniques in combination with criticality assessments, online monitoring and trend analyses of most critical components. Furthermore, signs were found that modeling and forecasting of production measurements are performed on some occasions as well. Therefore, it can be concluded from the situation analysis that activities that are related to PdM are performed within Fortum. It can thus be concluded that competencies beneficial for PdM practices already exist within the organization, such as gathering and analyzing production measurements. Due to this, barriers to a successful implementation identified, such as lack of training and lack of trust for the PdM techniques should be more easily managed (Mobley 2013; Thompson et al. 2014). Further, initial investments should be less demanding at Fortum than the general company, as already existent equipment can be utilized. For instance, the usage of vibration monitoring throughout Fortum can be utilized for PdM. Thus, measuring equipment such as vibration sensors are already in place. Furthermore, as knowledge of the techniques already exists within Fortum, it can be assumed that further education is less of a barrier than if the company was completely new to the technique.

Salonen (2011) states that guidelines, and a comprehensive vision, of PdM are of importance in order to succeed with an implementation. The results showed a large variety of answers, which indicates that no common guideline regarding the use of production measurements is in place.

5.1.1. The CNA-results

The CNA was used to further investigate the current maintenance maturity at three of Fortum's facilities. It should be noted that since the CNA is a very broad analysis, all data that was obtained during the interviews and are included in the resulting spider-charts have not been used for the final discussion. Instead, the CNA has been seen as a tool to create a more detailed mapping of Fortum's current maintenance maturity level. A high-level discussion of the CNA is presented below and the most important organizational factors related to PdM are highlighted.

5.1.1.1. General comments

As SKF stresses, knowledge of the current status of the maintenance organization is the key to identify potential for improvement. Regardless if the CNA is conducted at one or multiple facilities, it provides a snapshot that indicates the current level of maintenance maturity within the organization (SKF 2006). According to the initial questionnaire, Loviisa was considered Fortum's top performer – a further evaluation of Loviisa was thus of interest. Heat South Sweden, which represents a different segment of the plot, was selected for the questionnaire and Krångede was also included to represent the hydro division. By performing the CNA at these three facilities, a deeper knowledge of the current maintenance maturity at each plant was obtained. Together with the initial questionnaire this gives a more detailed picture of the current maintenance situation at Fortum as a whole.

The CNA-results further strengthened the view of Loviisa as a prominent facility in terms of maintenance performance – the majority of Loviisa's answers were inline with best practice and the facility outscored the industrial average at basically all points. Krångede was also well aligned with the "innovating" level, while the majority of the results of Heat South Sweden were considered to be at the "promoting" level. According to SKF:s model, these two levels, "innovating" and "promoting", are in general characterized by a high degree of optimizing rather than stabilizing efforts. Theses types of organization see the maintenance unit as an asset rather than a liability and as a tool for creating a competitive advantage (SKF 2006).

The categories of the CNA that concerns maintenance strategy and work control were assumed to be the most important enablers for PdM implementation. The questions in these categories includes criticality assessment, decision support system, priority system, change management process and RCFA, which are all closely linked to the key factors to a successful implementation according to the author's framework based on (EPRIGEN 1998; Groba et al. 2007) The answers to the most important factors for a PdM implementation are discussed below.

5.1.1.2. Criticality assessment

A well-defined and thorough criticality assessment is a key enabler to a successful PdM program since the predictive efforts should be focused on the most critical components in order to be cost effective (Mobley 2002; Gomez de Leon Hijes & Cartagena 2006). The CNA included a deeper evaluation of the method used for the assessment and the range of equipment that are included. All facilities outscored the industry average in terms of level of criticality assessment. Loviisa stood out as a best practitioner with an assessment based on an American standard that covers basically all equipment.

5.1.1.3. FMEA and RCFA

FMEA and RCFA are important tools in order to correctly identify what indicators of the concerned equipment that should be monitored to detect deterioration (Stamatis 2003). Loviisa specifically stated that virtually all planned work is derived form standardize processes such as FMEA and RCM. Moreover, all significant events are subjected to a RCFA. Standardized processes for planned work are also in place at Heat South Sweden and Krångede, but not to the same extent as at Loviisa. Furthermore, it is interesting to note that the share of significant events that is subjected to a RCFA at Krångede was considered to be inline with the firefighting level.

5.1.1.4. Planned versus unplanned maintenance tasks

The level of planned versus unplanned actions is an indicator of the level of reactivity of the facility. As Diamond & Marfatia (2013) points out, it is important to note that an organization that considers a PdM implementation should have a prior experience of working with PM and CBM since PdM is a further development of these maintenance types. All three plants reported a high level of planned maintenance tasks, which further indicates a high level of maintenance maturity. Furthermore, all three facilities scored high in terms of PM and CBM schedule compliance, which shows that the ability to perform planned work is high.

5.1.1.5. Decision support system

A firm decision support system that covers all recommended action of the PdM program is vital to success. If there are no work processes that indicate how the organization should act on the findings of the program, there is a high risk that the PdM efforts will be useless (EPRIGEN 1998; Groba et al. 2007). The CNA includes questions concerning the decision support for CBM actions, which can be used as an indicator for assessing how this process functions at the facilities. The results showed that Loviisa and Krångede are aligned with best practice in this case, while there is a lack of decision support at Heat South Sweden.

5.1.1.6. Asset register

Justifying the investments in PdM is considered one of the main difficulties and obstacles to implementation. Using a well-defined set of KPIs to measure and quantify the resulting improvements in maintenance performance is one way of illustrating the benefits of predictive actions (Kumar et al. 2013). A structured asset register is a requirement to enable the use of relevant KPIs. This was also strengthened by the maintenance managers at Heat South Sweden who pointed out that the current, unstructured asset register made the use of relevant KPIs difficult. The current asset register at Krångede was also considered to be less developed than the industry average. According to the CNA Loviisa stood out with a highly developed set of KPIs for measuring maintenance performance, which is closely related to highly organized asset register that also include virtually all equipment.

5.1.2. Discussion key takeaways

5.1.2.1. Overcoming barriers

The key takeaways in this study are derived from a combination of what is seen as important for a PdM implementation in the theoretical review, the archival review along with interviews conducted in this project. This project is not the first PdM-related project at Fortum, on the other hand several similar projects have been conducted. However, it can be argued that the previous projects have been to focus on technological aspects. Results from those projects, in accordance with findings of this project, have though shown that there are greater barriers to overcome in order to achieve a successful implementation. For instance, as Friedman (2013) argues, a lack of vision for the implementation will likely lead to failure. This is due to the fact that a PdM implementation not only involves technical changes, but strategic as well. This change of approach of maintenance affects the shop-floor level of maintenance work. As maintenance move from a corrective to a preventive approach, the value of the maintenance operations becomes more vague. Instead of physically repairing a broken down asset, the operations prevent the asset from ever failing. The approach to perform maintenance on visually healthy assets might be a difficult to implement. Here, barriers mentioned in this report such as lack of training and lack of trust in PdM technologies are of vital importance to overcome. A clear vision for the implementation of PdM will serve as a guideline for the maintenance, and thus the vague value of the maintenance will gain meaning.

A vital tool of overcoming barriers, according to literature, the utilization of KPI:s. As mentioned in this report, the objective of KPI:s is to help the organization to evaluate the maintenance procedures in order to be able to develop (Kumar et al. 2013). Further, KPI:s illustrate the value of maintenance actions and create a basis for decision-making concerning maintenance improvements. It is thus of importance, in order to properly evaluate a PdM implementation, that KPI:s are in place and utilized. In this project it has been seen that there are no standard way of measuring the performance of the maintenance organization within Fortum. Instead, the utilization of KPI:s ranges from being not structured at all in, to being utilized in a comprehensive way. Loviisa is a forerunner regarding measuring the performance of the maintenance organization, stating that KPI:s are utilized daily, weekly and monthly. This is an indication of the organization being structured, with a comprehensive foundation of information to justify potential improvements on.

5.1.2.2. Maximo and Qlikview

The uncertainties surrounding Maximo and Qlikview are of importance when it comes to measuring the maintenance performance of Fortum. Qlikview has great potential of being a consolidating tool of such measurements, with standard KPI-modules for each facility to utilize similarly. If this were implemented, it would be a visual and easily accessed tool for evaluating the maintenance operations of Fortum in a standardized way. As Kumar (2013) notes, development of KPI:s can aid in the effort for a cost-optimal strategy. Presently, however, too many uncertainties are surrounding the use of Qlikview. In this project, Qlikview was used to investigate to what degree the different maintenance organizations operates preventive versus corrective. It was however clear that the module used showed a result that could not be considered realistic, for instance as the number of work orders where deviating too much between the different facilities. The precise reason for these deviations is unclear, but can be related to dissimilarities in usage of the work order types in Maximo and inserting of data into Maximo at all. This is an obvious key factor for Fortum, as it serves as a basis for effective decision-making (SKF 2006). The processes related to the use of Maximo and Qlikview must be standardized in order for it to be a valuable source for comparison and benchmarking. If the data in Maximo were considered trustworthy, one would potentially be able to produce KPI:s that would declare the performance of the company. Thus, information would be provided regarding internal best practices and where to focus improvement investments. This would in turn lead to a more effective improvement work, as the sources of information would be available for all plants, leading to a unified understanding and acceptance of the information.

5.1.2.3. Initiatives seen – must be coordinated

This project has revealed a number of interesting previous projects related to PdM and current maintenance practices in line with PdM. However, it has been seen that solutions in many occasions has been developed locally, without any comprehensive cooperation within the divisions. This is obvious when investigating for instance different software solutions throughout Fortum. It can be argued that a comprehensive coordination of such projects would lead to greater transfer of knowledge, which in turn would assure that knowledge gained by one plant would be utilized by other parts of Fortum as well. This would be of great benefit, not only in a PdM implementation but for the general improvement work of Fortum as well.

5.1.2.4. Great internal experience

A finding of this project was that not only does Fortum perform activities in line with PdM, but there are vast experiences that can be of benefit for a PdM implementation within the organization as well. For instance, Loviisa is a top-performer with many of the vital parts in place for a successful PdM program. Therefore, it can be assumed that other plants, in progress of moving towards PdM, could benefit from learning from Loviisa. It can consider the use of KPI:s, how to perform criticality assessments or how to develop a change management process.

The internal consultancy agency, Power Solutions has extensive, valuable knowledge and experience, from many years of improvement work. They offer a full-scope service in which their Performance Center monitors, and produces recommendations for the plants to act on. They can also aid with specific services, for instance criticality analyses. An interesting note regarding PdM is that they have developed software for evaluation of CHP plants, in which a physical model of the normal state of the plant is compared with the actual state of the CHP to detect anomalies. Power Solutions also have teams specialized on turbines and generators. To have these functions within a company can be extremely valuable, if they are utilized correctly. However, it has been seen in this project that Power Solutions internally mainly acts in the Heat division within Finland, Baltics and Poland. This can be one reason for the rather high maintenance maturity found in these countries. The cooperation between Swedish plants and Power Solutions are almost non-existent. Interviews have pointed at the fact that cultural differences can be one reason for this.

The model of having centralized monitor centers is described earlier in this report. It has been proven successful as the complexity of building models, analysis etc. requires extensive competence and thus would a centralized function focus the need of such competence to only that center. This makes Power Solutions even more attractive, as it is a potential performance center for all of Fortum. This could both streamline the process of implementing PdM in Fortum, and reduce the issues of education, IT-solutions etc. that otherwise would exist for each separate plant. The fact that Power Solutions is part of Fortum does also mean that the risk of losing competence is eliminated.

5.1.2.5. Strategy important

According to Tsang (2002), the maintenance strategy should be serving as support for strategic issues such as allocation of resources and prioritization of operations. Further, cases presented in this report show that without an overarching vision, i.e. a strategy, the likeliness of failure increases. Due to this, it is of importance to incorporate PdM in the strategic discussions of Fortum. As investments in form of education and equipment are needed, it is of importance that PdM gets appropriate strategic priority.

5.1.1. Summarizing discussion

The main idea of predictive maintenance is to detect beginning equipment deterioration at an early stage and thus decrease the need for corrective actions and costly downtime. A PdM program can serve as a valuable tool for reducing the cost of maintenance actions by increasing the control of the equipment condition and provide important information for efforts aiming to optimize the maintenance as well as the production processes (Carnero 2006; Mobley 2002). PdM is a further development of CBM and should be viewed as a complement and addition to an existing maintenance concept rather than a separate, stand-alone solution. It is thus essential that an organization that is considering an implementation of PdM has prior experience of preventive and condition based approaches to maintenance (Diamond & Marfatia 2013).

The purpose of this thesis was to evaluate the potential for PdM at Fortum by investigating prerequisites and barriers to a PdM implementation. By assessing the alignment of Fortum's current maintenance practices with PdM and identifying barriers for an implementation of a PdM program, the potential for predictive maintenance at Fortum could be evaluated.

The results of this thesis have shown that the core of a PdM program is the handling and usage of production data in order to detect the onset of performance degradation. However, a well-established organizational structure is required in order for such a program to be successful. Based on the output of this thesis, Fortum’s facilities are in general considered to be at the level of maintenance maturity that is required for a development of a PdM program. In Fortum's case, moving towards PdM is a natural next step in order to increase the control of equipment condition and to decrease the level of costly downtime, which is in general a key issue for heat and power producers.

5.2. Methodology discussion

As Yin (2003) writes, utilizing case study as a research method is appropriate when the research considers a contemporary set of events, over which the researchers has no control over. With this in mind, the main research method is considered to have functioned as expected. The method enables the researcher to utilize information from different sources to draw own conclusions, which was of benefit in this project as much valuable data were gathered in unstructured interviews, internal documents, presentations etc. within the company. Also, as a questionnaire and a benchmarking tool were incorporated in the case study, the resulting information was considered comprehensive enough.

A questionnaire served as a basis for the data collection regarding the situation analysis. There are several uncertainties related to utilizing questionnaires as research method. Due to the wide scope of the situation analysis, and the little knowledge on beforehand of possible answers to some of the questions, more open-ended questions could have been of benefit for the analysis, as Bohgard et al (2008) writes. The close-ended questions with predefined answers did simplify the analysis part of the project, but did potentially make the respondents choose answers they did not fully agree with, but considered to be the best out of the available answers. It was considered hard to define questions that on one hand was focused enough to produce valuable data for the analysis, but on the other hand was broad enough to be identifiable for all respondents, within all three divisions. In retrospective, it could have been of interest to customize some of the questions for each of the divisions.

As always when conducting a questionnaire, the subjectivity of the respondent must be noted. Factors such as the work position and responsibilities of the respondent may affect the answers. It has been strived for to find as similar respondents as possible in this project. However, due to the different organizational structures of the different divisions the work positions of the respondents' ranges from maintenance engineers at some plants to the region managers at Hydro. It is however assumed that all respondents are familiar with the maintenance operations of their interest and it is therefore not considered to be a major problem.

The importance of the results of the questionnaire serving as an indicator must also be emphasized. As the questionnaire included heat, hydro and nuclear, and due to the limit of time, the level of detail in the situation analysis was rather limited. In turn, this led to data with a certain level of detail that can be argued to be a bit too vague to serve as a stand-alone analysis. Therefore, the purpose of serving as an indicator for further analysis was considered appropriate.

Another point of uncertainty was how to evaluate and present the outcome of the questionnaire. No appropriate pre-developed framework for this was found and therefore the guidelines for grading were constructed by the authors. Even though the grades were based on the literature review, subjective interpretations of the theoretical information are inevitable. However, since the grading was performed in a similar manner for all respondents it was considered an equal process. Further, the purpose of the grading was an internally relative comparison, hence eventual subjective opinions can be accepted if they are applied equally to all responses.

The objective of the maintenance maturity plot was to visually present an internally relative comparison of parameters important for PdM between the facilities of Fortum. The fact that it is a relative, internal comparison, no conclusions regarding the performance of the facilities can be drawn only by this result. Instead, it was thought to function as an indicator on what facilities that are more capable of a PdM implementation than others. In turn, this would serve as decision support on what facilities to include in the benchmark analysis.

SKF's Client Needs Analysis (CNA) is a proven, powerful benchmarking tool based on a wide set of data. Thus, the resulting mapping based is considered to be highly reliable. However, since a few of the questions included in the CNA are rather open-ended, it should be noted that the subjective judgment of the respondents might affect the results. According to the CNA experts at SKF, the response to these questions is in general more optimistic than the actual case.

6. Conclusions

In this section, the findings in this thesis are summarized in concise answers to the stated research questions.

The purpose of this thesis was to evaluate the potential for PdM at Fortum by identifying barriers and requirements for a successful implementation of a PdM program and to investigate the current alignment with PdM practices. Two research questions where stated and the resulting answers to these questions are presented below.

RQ1. What are the possible barriers to a successful implementation of PdM at Fortum?

Based on the findings in the archival research and the literature review, a set of key barriers to a successful PdM implementation was identified:

- Difficulties in justifying the investment costs in PdM technology
- A lack of organizational support
- A lack of trust in predictive technology

The ability to justify the investment costs by illustrating an increased performance of the maintenance organization is important. This requires a well-defined set of KPI:s to measure improvements and quantify the benefits of a PdM implementation - what you don't measure, you do not know. PDS solutions, that are considered state-of-the digital solutions for PdM, have been tested and evaluated at Fortum a prior to this study. The planned further actions have however not been implemented, largely due to the fact that the investment cost could not be justified.

Standard processes for how to perform the data analysis and a decision support process that clarifies how the organization should act on the resulting recommendations are crucial to the success of the program. There have been several investigations of PdM related techniques and efforts taken to move towards PdM a prior to this study. However, there are no current, Fortum-wide vision of developing the maintenance strategy to include a PdM program. Software for performance and condition monitoring are used at some facilities, but there are no standards for how this data should be analyzed. There are also a lack of standards for division of responsibilities that clarifies who will perform the analysis and who will be in charge of the decision making based on these analysis. If there is no firm organizational support for the PdM program, there is a high risk that PdM tasks are not performed or subjected to a low priority. Without a strategy for how to act on the recommendations, the PdM program will be useless.

The concerned stakeholders, including the maintenance crew and the management team, need to understand that a PdM program is a long-term solution and not a "quick-fix". Moving towards a PdM approach will likely not result in immediate financial gain. A lack of trust in the resulting prediction of the program, a higher reliance of the operators own diagnostic ability and an expectation of short term economical benefits are common reason of a failed implementation, according to the findings in the literature. The archival review showed several examples of reliance on individual knowledge and experience rather than standardized monitoring methods concerning scheduling of maintenance actions. An upcoming competency gap among new maintenance personnel was also pointed out as a big issue. On the other hand, there is a vast internal expertise as Fortum's own O&M consultant agency, Power Solutions, has great experience from working with PdM related projects both internally and externally. However, there actions are mainly focused on Heat Finland.

RQ2. To what degree are the maintenance practices at Fortum aligned with PdM practices?

This question was answered based on the findings in the literature concerning requirements for a PdM implementation and the output of the situation analysis and the CNA. PdM related practices that were discovered during the archival research were considered as well.

According to the literature, a PdM program should be seen as an addition to an existing maintenance concept rather than as a separate solution. PdM is most effectively used as a part of a maintenance strategy that consists of a mix of preventive and corrective maintenance types. A successful PdM program requires a well-defined criticality assessment since the predictive efforts should be focused on the most critical equipment in order to be cost effective. Moreover, an understanding of the characteristic of the concerned equipment is vital in order to identify the indicators that are to be monitored to detect equipment deterioration.

The situation analysis included in this thesis has shown that production measurements are currently being used for maintenance purposes at the majority of Fortum's production units. Trend analysis is conducted in some cases, but no standard work processes concerning PdM are in place, which is indicated by the fact that techniques for equipment monitoring and the data handling differ between and within the divisions.

The results of the CNA showed that the concerned facilities had vast experience from working with PM and CBM approaches which is a key requirement since PdM is a further development of these maintenance types. The plants subjected to the CNA were selected based on their placement in the maturity grid. The grid together with the CNA gives a wider picture of the current alignment with PdM practices and based on these findings it can be concluded the general level of maintenance maturity at Fortum are in line with the requirements for PdM. Furthermore, the archival research indicated that PdM related actions are taken to some extent at certain facilities.

With background in the above-mentioned findings, it be concluded that Fortum generally has high potential of moving towards PdM on an operational and technological level. The main obstacle is instead found at a strategic level, as standard processes for how to utilize production measurements are missing. No common methods, tools or software are identified, hence different solutions has emerged locally. This has resulted in a wide range of different processes for utilizing production measurements. Subsequently, no standard best way has been developed.

6.1. Suggested future research

This thesis has been focused on the current situation at Fortum and the potential for PdM at Fortum has been considered. An interesting extension to this project would be to investigate if the resulting barriers are applicable to other companies within the process of manufacturing industry as well. Furthermore, this thesis has not considered the practical operations of trend analysis or the preferred structure of a decision support system. Thus, it would be valuable to conduct a deeper evaluation to establish best practices in terms of the practical operations of trend analysis and the design of decision support systems.

For Fortum it would be of interest to and conduct a more in-depth mapping of the current usage of vibration measurements. By identifying a “Fortum way” for vibration monitoring and defining standards for analytics of data from vibration measurements, a platform for predictive maintenance could be established. This result could be used to show the economical benefits of PdM and also function as an internal point of reference that all units should strive for in terms of PdM. With a firm organizational structure for how PdM is conducted in place, this platform could be further extended to include other monitoring techniques such as PDS solutions.

Furthermore, the CNA-results include more information that could be of great value for identifying potential room for improvement at each concerned facility. These results could be studied more in detail in order to gain a deeper knowledge of the overall performance of the maintenance organization at these plants.

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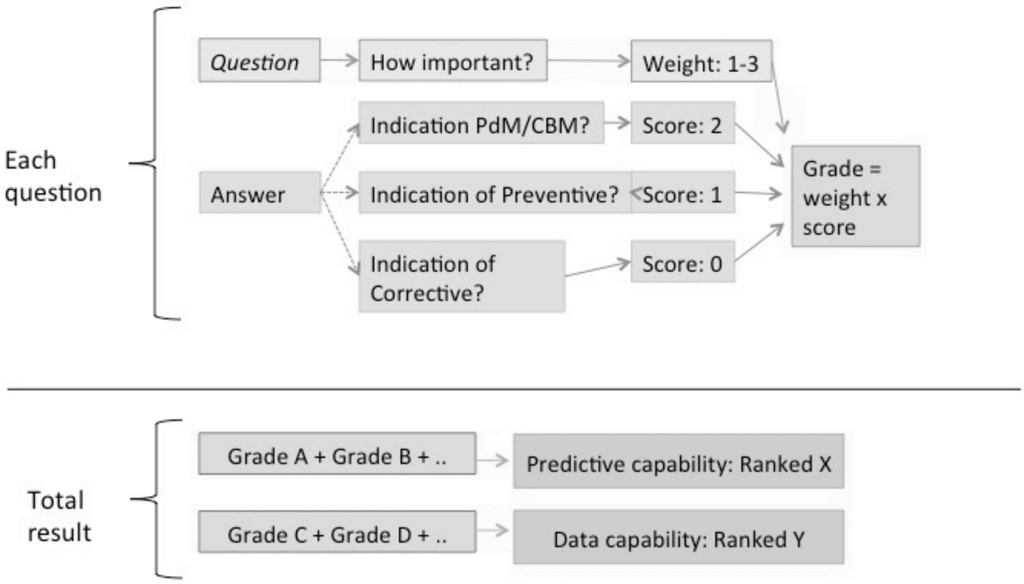
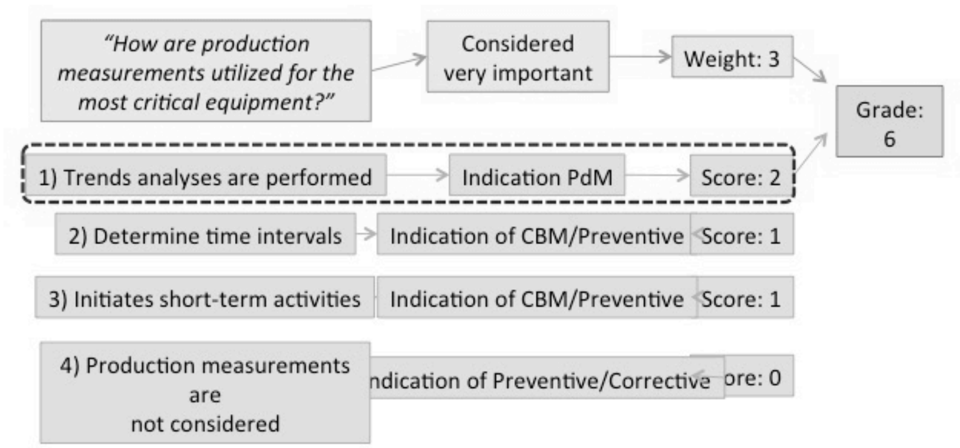
Appendix A

Grading scheme

The grading process:



The grading process – example:



Appendix B

Situation analysis questionnaire

This questionnaire aims at evaluating the current maintenance practices of Fortum with focus on production measurements.

Used terminology standard: SSEN-13306.

Work position:	
Concerned plant(s):	

Analytical maturity

Q1 **Are there any common standard work processes for predictive maintenance in your region?** **1**

- Yes ☐ 2
- No ☐ 0
- Not to my knowledge ☐

Q2 **How are production measurements (i.e. flow rate, temperature, pressure etc.) mainly utilized for maintenance operations? (Multiple answers are possible.)** **3**

- Maintenance activities are scheduled based on analysis of historical production measurements and trends ☐ 2
- To schedule long term maintenance activities ☐ 1
- To determine time intervals between maintenance activities (e.g. time between change of pump seals, time between oil change. etc) ☐ 1
- To initiate short term maintenance activities (i.e. work orders are created based on production measurements) ☐ 1
- Production measurements are normally not considered for maintenance purposes ☐ 0

Other purposes (please specify)

Q3 **For the component/equipment that is regarded as the most critical to the operations of the plant, maintenance is based on:** **3**

- On-line monitoring and analysis of data trends ☐ 2
- On-line monitoring focused on current equipment condition ☐ 1
- Current equipment condition ☐ 1

	Predetermined time-intervals	1
	Failure of the equipment	0
	Criticality is not considered for maintenance	0

Comment

Q4	**Which software are used for analyzing production measurements in maintenance purpose? (E.g. Maximo, Qlikview, Excel, etc.)**	**1**
	Please state below:	
		0
		1
		2
Q5	**How are production measurements inserted in Maximo? (Multiple answers are possible)**	**1**
	Relevant data is inserted manually	1
	Relevant data is transferred to Maximo automatically from data base	2
	Data is not entered into Maximo	0

Comments:

Q6	**Are Fortum Power Solutions assisting in the maintenance operations?**	**-**
	Yes	-
	No	-
Q7	**Has any investigation of the potential for implementing "predictive maintenance" been done at the plant/in the region?**	**2**
	Yes	2
	No	0

Comments

Measurements

Grading: Final score is the weight of each main question (Q8-Q11) times the resulting score of the sub-questions

Resulting score of sub-questions: score 0-5=1 point, 6-above=2 points

Q8	**Lubricating oil analysis**	**2**
Q8.1	*Are these types of measurements performed? (If no, proceed to question 9)*	
	Yes ☐	-
	No ☐	-
Q8.2	*Which of the following analysis are carried out? (Multiple answers are possible)*	
	Analysis of oil properties ☐	-
	Analysis of contaminants ☐	-
	Analysis of wear debris from machinery ☐	-
Q8.3	*On what types of equipment are this analysis performed?*	
	Pumps ☐	More than 1 box ticked = 2 points
	Electric motors ☐	1 box ticked = 1 point
	Transformers ☐	
	Heavy equipment/cranes ☐	
	Other, please specify	
Q8.4	*The measurements are performed based on:*	
	Fixed time intervals ☐	1
	The measurements are continuous ☐	2
	Not applicable ☐	-
Q8.5	*The measurements are done (Multiple answers are possible):*	
	Manually ☐	1
	Automatically ☐	2

By maintenance staff on-site	☐	-
At laboratory	☐	-

Q8.6 *How is the data stored (multiple answers)?*

Local database	☐	1	
Central database	☐	2	
Not digitally	☐	0	
Data is not stored at all	☐	0	

Q8.7 *For how long is the data stored?*

Less than a month	☐	0	
Up to 1 year	☐	1	
More than 1 year	☐	2	
There is not fixed time for data storage	☐	2	If data stored digitally, else 0

RESULTING SCORE FOR SUBQUESTIONS:

Q9 **Vibration analysis** **3**

Q9.1 *Are these types of measurements performed? (If no, proceed to question 10)*

Yes	☐	-
No	☐	-

Q9.2 *On what types of equipment are this analysis performed?*

Pumps	☐	More than 1 box ticked = 2 points
Electric motors	☐	1 box ticked = 1 point
Turbines	☐	
Heavy equipment/cranes	☐	

Other, please specify

Q9.3 *The measurements are performed based on:*

Fixed time intervals	☐	1
The measurements are continuous	☐	2

	Not applicable		-	
Q9.4	*The measurements are done:*			
	Manually	☐	1	
	Automatically	☐	2	
Q9.5	*How is the data stored (multiple answers)?*			
	Local database	☐	1	
	Central database	☐	2	
	Not digitally	☐	0	
	Data is not stored at all	☐	0	
Q9.6	*For how long is the data stored?*			
	Less than a month	☐	0	
	Up to 1 year	☐	1	
	More than 1 year	☐	2	
	There is not fixed time for data storage	☐	2	If data stored digitally, else 0
	RESULTING SCORE FOR SUBQUESTIONS:			
Q10	**Infrared thermography**		**1**	
Q10.1	*Are these types of measurements performed? (If no, proceed to question 11)*			
	Yes	☐	-	
	No	☐	-	
Q10.2	*On what types of equipment are this analysis performed?*			
	Pumps	☐		More than 1 box ticked = 2 points
	Electric motors	☐		1 box ticked = 1 point
	Condensers	☐		
	Heavy equipment/cranes	☐		
	Circuit breakers	☐		
	Valves	☐		
	Heat Exchangers	☐		

	Electrical Systems	
	Transformers	
	Other, please specify	

Q10.3	*The measurements are performed based on:*	
	Fixed time intervals	1
	The measurements are continuous	2
	Not applicable	-
Q10.4	*The measurements are done:*	
	Manually	1
	Automatically	2
Q10.5	*How is the data stored (multiple answers)?*	
	Local database	1
	Central database	2
	Not digitally	0
	Data is not stored at all	0
Q10.6	*For how long is the data stored?*	
	Less than a month	0
	Up to 1 year	1
	More than 1 year	2
	There is not fixed time for data storage	2 If data stored digitally, else 0
	RESULTING SCORE FOR SUBQUESTIONS:	
Q11	**Ultrasonic analysis**	**1**
Q11.1	*Are these types of measurements performed? (If no, proceed to question 12)*	
	Yes	-
	No	-
Q11.2	*On what types of equipment are this analysis performed?*	

	Pumps	☐	More than 1 box ticked = 2 points
	Electric motors	☐	1 box ticked = 1 point
	Condensers	☐	
	Valves	☐	
	Electrical Systems	☐	
	Transformers	☐	
	Other, please specify		

Q11.3	*The measurements are performed based on:*		
	Fixed time intervals	☐	1
	The measurements are continuous	☐	2
	Not applicable		-
Q11.4	*The measurements are done:*		
	Manually	☐	1
	Automatically	☐	2
Q11.5	*Is the data from these measurements logged and stored?*		
	Yes	☐	1
	No	☐	0
Q11.6	*How is the data stored (multiple answers)?*		
	Local database	☐	1
	Central database	☐	2
	Not digitally	☐	0
	Data is not stored at all	☐	0
Q11.7	*For how long is the data stored?*		
	Less than a month	☐	0
	Up to 1 year	☐	1
	More than 1 year	☐	2
	There is not fixed time for data storage	☐	2 If data stored digitally, else 0

RESULTING SCORE FOR SUBQUESTIONS:

Q12 **Is on-line monitoring of any equipment performed?**

Yes

No

If yes, please specify what equipment is monitored

Q13 **Which area of the plant would you consider the MOST developed in terms of maintenance?** -

Q14 **Which area of the plant would you consider the LEAST developed in terms of maintenance?** -
