DEVELOPMENT OF PREVENTIVE MAINTENANCE – CASE STUDY A STEEL MILL

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Mechanical Engineering, Master's Thesis

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ABSTRACT

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Development of preventive maintenance – case study a steel mill

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89 pages, 17 figures, 12 tables and 6 appendices

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Keywords: Maintenance, RCM, Preventive Maintenance, Development, Failure, Criticality Classification of Equipment, FMEA, Maintenance Management System, Steel Industry

The aim of this thesis is to develop and modernize the preventive maintenance of Ovako Imatra steel mill as part of the renewal project of the maintenance management system. Current preventive maintenance plans of the mill are partly outdated, in addition to which failures are to be anticipated and prevented by various risk analysis methods. Aim is to reduce failures, identify the most critical equipment and components and improve mill reliability by optimizing preventive maintenance. Triangulation components are used as research methods; literature review, risk analysis methods and databases of Ovako. Thesis is limited to the mechanical equipment of the steel mill and heavy bar mill. Thesis determinates the most faulty equipment in the mill based on mechanical failure information. Criticality classification of equipment, as well as failure mode and effects analysis, provide methods to develop preventive maintenance in the direction of reliability centered maintenance (RCM). The optimization of preventive maintenance instructions ensures the need for preventive maintenance of the current equipment base, aiming to correct maintenance intervals and minimize failures. In the results of the thesis, the most faulty areas and equipment were determined for case examples (PSK6800 and FMEA). Criticality classification of equipment and FMEA were used to assess the criticality of the most faulty equipment and possible failure modes and their effects. Information from case examples, my own experience and literature review materials were utilized in the optimization of preventive maintenance instructions. Optimizations were completed for the new maintenance management system, Pinja Novi.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Energiajärjestelmät

Konetekniikka

Teemu Havulinna

Ehkäisevän kunnossapidon kehittäminen – case-esimerkki terästehdas

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Avainsanat: Kunnossapito, RCM, Ehkäisevä Kunnossapito, Kehittäminen, Vikaantuminen, Kriittisyysluokittelu, Vika- ja vaikutusanalyysi, Kunnossapitojärjestelmä, Terästeollisuus

Tämän tutkimuksen tavoitteena on kehittää ja uudistaa Ovako Imatra terästehtaan ehkäisevää kunnossapitoa osana kunnossapitojärjestelmän uudistamisprojektia. Tehtaan nykyiset ehkäisevän kunnossapidon ohjelmat ovat osittain vanhentunutta tietoa, jonka lisäksi vikaantumisia halutaan ennakoida ja estää eri riskianalyysimenetelmin. Tavoitteena on vikaantumisten vähentäminen, kriittisimpien laitteiden ja komponenttien tunnistaminen sekä tuotantolaitoksen luotettavuuden parantaminen optimoimalla ehkäisevää kunnossapitoa. Tutkimuksen menetelminä käytetään triangulaation osatekijöitä; kirjallisuuskatsausta, riskianalyysimenetelmiä ja Ovakon tietokantoja. Tutkimus rajataan tehtaan teräs- ja karkeavalssaamo -tuoteyksikön mekaanisiin laitteisiin. Tutkimuksessa määritetään tehtaan vikaantuneimmat laitteet mekaanisten häiriötietojen perusteella. Laitteiden kriittisyystarkasteluilla sekä vika- ja vaikutusanalyysien avuilla tuodaan työkaluja, joilla ehkäisevää kunnossapitoa voitaisiin kehittää luotettavuus keskeisen kunnossapidon (RCM) suuntaan. Ehkäisevän kunnossapidon ohjelmien optimoinnilla varmistetaan nykyisen laitekannan ehkäisevän kunnossapidon tarve, tavoitellen huoltovälien oikeellisuutta ja vikaantumisten minimoimista. Tutkimuksen tuloksissa vikaantuneimmat alueet ja laitteet määritettiin case-esimerkkejä (PSK6800 ja FMEA) varten. Kriittisyysluokittelun ja vika- ja vaikutusanalyysien avuilla arvioitiin vikaantuneimpien laitteiden kriittisyyksiä ja mahdollisia vikamuotoja ja niiden vaikutuksia. Ehkäisevän kunnossapidon ohjelmien optimoinnissa hyödynnettiin case-esimerkkien tietoja, omaa kokemustani sekä kirjallisuuskatsauksen materiaaleja. Optimoinnit tehdään uuteen kunnossapitojärjestelmään.

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I carried out this thesis in the maintenance organization of Ovako Imatra Oy Ab, where I have already worked in various positions for the three previous summers. It has been great to work for a good employer while developing my own skills and expertise. Thank you, thus, to Ovako for the opportunity to write this master’s thesis. Thank you also to the entire maintenance organization of Ovako Imatra for the past years and most recently for the support related to my master’s thesis. Many thanks to Seppo Räihä, M.Sc. (Tech.), the supervisor of both my bachelor's and master’s thesis, for his wise comments and good guidance. Thanks also to the examiners of my thesis, Docent Harri Eskelinen and Kimmo Kerkkänen, D.Sc. (Tech.), for the great comments and support during the thesis!

The implementation of the thesis fell precisely in the midst of Covid-19, which made more traditional meetings impossible or held in a small group. Fortunately, the meetings were held very smoothly. Thanks to everyone who attended the meetings.

Many thanks also go to my fiancée, Sophia, for her support and encouragement. Both my own parents and those close relatives for their constant encouragement in my studies. In addition, I would like to thank all my fellow students who I have been able to get to know during my studies at LUT University.

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SYMBOLS AND ABBREVIATIONS

Abbreviations

6S	Lean methodology; Sort, Set in order, Shine, Standardize, Sustain, Safety
CC	Continuous Casting
CMMIS	Computerized Maintenance Management Information System
CMMS	Computerized Maintenance Management System
EAF	Electric Arc Furnace
EAM	Enterprise Asset Management
FMEA	Failure Mode and Effects Analysis
IIoT	Industrial Internet of Things
IoT	Internet of Things
KPI	Key Performance Indicators
LAN	Local Area Network
LF	Ladle Furnace
LTA	Logic (Decision) Tree Analysis
ML	Machine Learning
MTBF	Mean Time Between Failures
PdM	Predictive Maintenance
PM	Preventive Maintenance
PSK	PSK Standards Association
RCM	Reliability Centered Maintenance
RPN	Risk Priority Number
SAMI	Strategic Asset Management Inc.

SFS	Finnish Standards Association
SQL	Structured Query Language
TPM	Total Productive Maintenance

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1. Introduction

Production facilities are made up of many different stakeholders and each of these has a huge impact on the smooth operation of the entire production facility. In particular, maintenance has a significant impact on mill productivity. Without effective maintenance, production targets cannot be achieved. In this case, the reliability and preventive maintenance of the equipment play a particularly important role, which will be discussed in more detail as the thesis progresses.

This master's thesis deals with industrial maintenance and its development. The thesis particularly focuses on the development of preventive maintenance in a steel company. Consider the importance of preventive maintenance in fault-prone industries. The introduction section describes in more detail the background of the thesis, research problem, methods and questions, limitations and introduces the case company, Ovako.

1.1 Background

The steel industry has been hit hard by the Covid-19 pandemic. The pandemic that began in late 2019 was not yet immediately reflected in the steel industry or orders received. However, 2020 was a challenging year for the entire steel industry. Towards the end of 2020, there were already strong signs of recovery and 2021 has been a very bright year for the steel industry. Ovako, which manufactures special steels in particular, has a record order book. During the current year, demand for steel has therefore been very high, which has put great pressure on production facilities. This is also strongly reflected in the maintenance organizations. Maximum productivity is desired for production equipment to keep delivery accuracy at a high level. Consequently, equipment and machine of the production mill must also function properly to achieve the production objectives. Maintenance, especially preventive maintenance, has a significant impact on the availability and functionality of equipment. Preventive maintenance is used to detect premature equipment failures and to be able to react to failures in the right ways.

Due to the current high production pressure, maintenance operations in the steel industry are under a particularly heavy load. Equipment failures increase due to their heavy load and ageing. The case company's preventive maintenance instructions also require optimizing and changes. In the case of Ovako, in addition to production pressure, the maintenance organization is introducing a new maintenance management system, which is one of cause why the preventive maintenance instructions must be updated and optimized. So overall, maintenance operations requires constant development in the face of new challenges.

1.1.1 Case company – Ovako Imatra steel mill

Ovako Imatra steel mill belongs to the Ovako Group and is one of its most important production mill. Ovako Imatra has about 600 employees. The long history of Imatra steel mill dates back to 1915, when the first steel mill, Elektrometallurgiska Ab, was established. Imatra steel mill produces technically high-quality steels, for example the automotive and engineering industries. There are more than 250 different steel grades that can be produced in Imatra. The most important product is easy-to-machine M-Steel, which is used in transmission components and mechanical engineering solutions. In Imatra, high-quality bearing steels are also produced to an increasing extent for industrial use. (Ovako, 2021a) Recycled steel scrap is used as a raw material at Imatra mill. Ovako's emissions are very low precisely due to recycling scrap and sustainability investments. The CO_2 emissions produced by Ovako are 80 % lower than the global average. (Ovako, 2021c) As well as the beginning of 2022, Ovako´s steel production to be carbon-neutral (Ovako, 2021b).

Ovako Group is part of Nippon Steel Corporation. Nippon Steel Corporation is a large Japanese steel products company. Nippon Steel Corporation consists of many different subsidiaries worldwide, including Sanyo Special Steel, which acquired Ovako Group in 2019. Nippon Steel is the world's fifth largest steel producer. In 2020, the entire corporation produced 41.58 million tonnes of steel (Statista, 2021). Nippon Steel produces steel for many different applications and their products include, for example plates and construction products, flat products, bar and wire rod, pipe and tube and stainless steel. (Nippon Steel, 2021)

1.2 Objective

The main objective of the thesis is to develop and modernize the preventive maintenance of Ovako Imatra steel mill as part of the renewal project of the maintenance management system. Objectives are, among other things, to reduce failures, identify the most critical equipment and components, and improve mill reliability. Thesis determines the most faulty equipment in the mill based on mechanical failure information. The criticality classification of equipment, as well as failure mode and effects analysis, provide tools for developing preventive maintenance in the direction of reliability centered maintenance (RCM). At present, preventive maintenance instructions are partly outdated information. The preventive maintenance instructions must be optimized in terms of their scope and coverage, to meet current equipment base of the mill and the need for preventive maintenance required by equipment. During the project, preventive maintenance instructions for the most faulty equipment in the steel and heavy bar mills will be optimized for the new maintenance management system. The objective is to optimize equipment maintenance intervals and minimize failures.

1.3 Research problem

One of the research problems is that the thesis should find out how to determine the best possible operating and maintenance methods, so that possible failures can be predicted in time and prevented (preventive maintenance) before they occur. Here, optimizing preventive maintenance instructions plays an important role. But the variety of equipment base and current entrenched practices increase to the challenge of optimizations. In addition, it is challenging to find the correct ways to develop preventive maintenance plans through failure information, criticality classification of equipment and failure mode and effects analysis. The implementation of a new maintenance management system and its effects on preventive maintenance also cause a major research problem. The new maintenance management system is more agile and customizable than the old system in many sub areas. However, can the system be used in the best possible way for the benefit of preventive maintenance?

1.4 Research methods and questions

Qualitative research methods are utilized as research methods. Research methods form a triangulation, which consists of a literature review, utilization of Ovako's databases and risk analysis methods. The most important aspect of triangulation is Ovako's databases and their utilization. Databases provide information on equipment failures, the number of failures and current preventive maintenance routines and maintenance plans. Literature review of the thesis consists of maintenance development, preventive maintenance, equipment failure and reliability centered maintenance. The third method of triangulation is to utilize risk analysis methods. Risk analysis methods examine the selected most faulty equipment from the perspective of failure mode and effects analysis (FMEA) as well as criticality classification of equipment. Figure 1 shows an illustrative figure of triangulation.

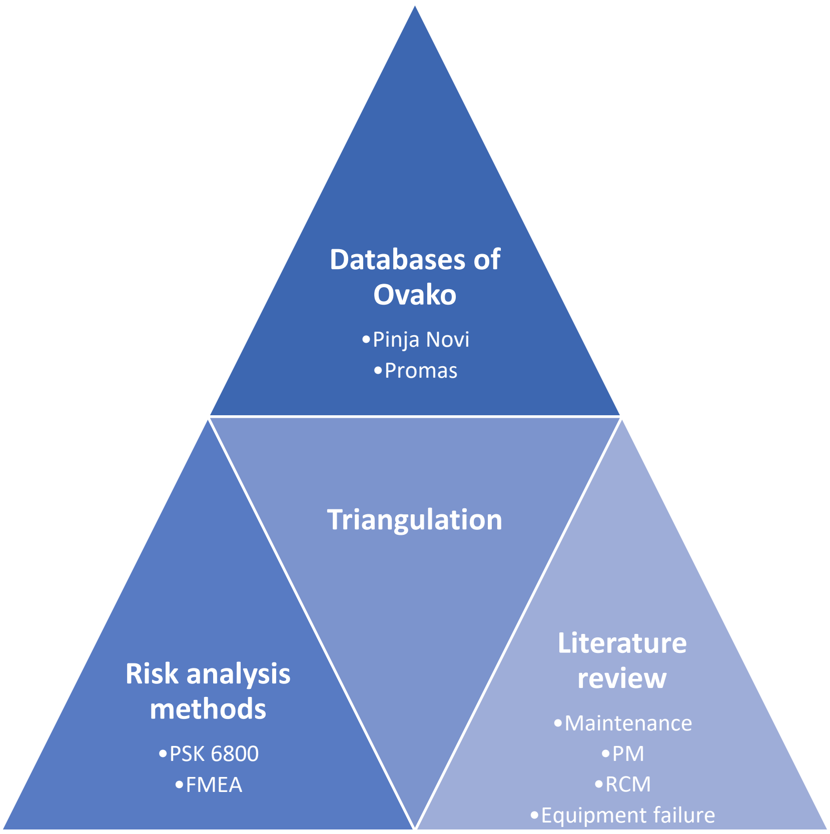

Figure 1. Triangulation of the thesis.

Research questions related to the thesis are listed separately below. Research questions support objectives and research problem of the thesis and provide answers to the completion of objectives. The main research question is below:

- *What is the reason for the challenges of optimizing preventive maintenance and its plans, and why should the risk analysis methods presented be included in the development of preventive maintenance?*

And the sub-questions are:

- *What want to be achieved the optimizing of preventive maintenance instructions and how them will be optimized in the future?*
- *How can the benefits of new maintenance management system be exploited in the development of preventive maintenance?*

1.5 Scope and limitations

The thesis theory part is limited to dealing with maintenance in general in industry from the reliability perspective. The review is limited in particular to preventive maintenance, equipment failures and reliability centered maintenance (RCM). Results of the thesis are limited to handling areas and equipment of the steel mill and heavy bar mill. The examination is limited to mechanical equipment or sub-assemblies of equipment in a limited area. Based on equipment failure information, the data is limited to the most faulty equipment or lines of the steel mill and heavy bar mill. The results section evaluations the development of preventive maintenance instructions for these selected equipment or lines and illustrates with case examples how the failure and criticality of these equipment can be analysed.

1.6 Structure of the thesis

This thesis follows the IMRAD structure and consists of sub-assemblies in accordance with it. The abbreviation comes from the words Introduction, Method, Result, Analysis and Discussion. First, the introduction section provides background information related to the thesis, objectives and limitations. The section also presents research methods, problems and questions. In addition, the case company and production mill are briefly introduced. Theory and methods section consists of a literature review focusing on maintenance, its types, preventive maintenance, reliability centered maintenance and failures of equipment. The section also presents used methods, i.e. risk analysis methods and an overview of Ovako's databases. Theory and methods of the thesis provides background information for achieving the results. Results and analysis section consists of reviewing the desired results and their analysis. Results of the thesis consist of data from Ovako's databases, case examples and optimization of preventive maintenance instructions. Results include, among other things, the most faulty equipment or lines, the process of optimizing the preventive maintenance instructions and the results of the case examples. Finally, results of the thesis, key findings, reliability and validity of the research and ideas for further development are discussed.

2. Theory and methods

Theory and methods used in the thesis are presented in this section. Theory consists of a scientific literature review. Methods include the use of risk analysis methods and databases of Ovako. Theory and methods of the research support the formation of thesis results. The end of the section explains how the obtained results are achieved with the help of theory and methods.

2.1 Maintenance in general and prevention of failures by preventive maintenance actions

This literature review examines the development of maintenance, maintenance types and strategies, reliability centered maintenance, preventive maintenance and its planning, and failures of equipment. The purpose of this section is to provide information on how failures can be prevented by preventive maintenance actions. The references for the literature review are based on scientific articles, books and standards.

2.1.1 Definition, development and challenges of maintenance

There are many definitions of maintenance in different literature sources and standards. And there is not just one valid definition of maintenance. For example, SFS-EN 13306 defines maintenance as consisting of all technical, managerial and administrative actions during the life cycle of object or equipment. The purpose of these actions is to maintain or restore the functionality of object or equipment to such an extent that object or equipment can perform the required function. (SFS-EN 13306, 2017, p. 5) The PSK Standards Association also defines maintenance in accordance with standard SFS-EN 13306. PSK 6201 defines maintenance as follows:

"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." (PSK 6201, 2011, pp. 2-3)

The literature specifies that the purpose of maintenance is to keep physical fixed assets in a condition where they can perform the tasks assigned to them, when needed. This means ensuring dependability. The aim is to maintain operational capacity, i.e. prevent equipment failure and maintain production quality. Important maintenance tasks include keeping equipment safety, improvement, preventive maintenance, breakdown maintenance and correcting design errors. Maintenance must also monitor the correct operation and develop both operation and maintenance skills. In addition to this, maintenance involves analysing the data collected over the life cycle of equipment and making a decision based on it. (Järviö & Lehtiö, 2017, p. 19) However, maintenance does not include actions that aim to improve equipment performance compared to the original performance. In addition to actual actions, i.e. technical execution, maintenance also includes all related administrative and management actions. (Mikkonen, 2009, p. 26)

Like other organizations of companies, maintenance is changing and evolving very quickly. For industry, the term Industry 4.0 has been used for a few years to refer to the next more advanced phase of industrial transformation (Culot, et al., 2020, pp. 1-2). Following maintenance philosophy has also been developed for maintenance, termed Maintenance 4.0. Maintenance 4.0 is wider and more advanced than, for example, Maintenance 3.0. Maintenance 4.0 philosophy is considered to have started at the beginning of the 2020s, so it is still very slightly used and a new thinking philosophy in maintenance industry. Maintenance 4.0 includes IoT, big data and additive manufacturing, among others, that have not yet been utilized in Maintenance 3.0 philosophy. Maintenance 4.0 is developing maintenance in an increasingly autonomous direction. However, the familiar functions of maintenance are also retained in Maintenance 4.0. (Navas, et al., 2020, p. 856)

Often production and maintenance do not cooperate enough or share information which creates inconvenience to maintenance operations. It may happen that time planned for maintenance is put into production in order, among other things, to catch up with overdue schedule. On the other hand, it can also be challenging to convince your production that maintenance needs time to operate before you are in a situation where equipment is operating reliably. If maintenance is seen only as breakdown maintenance, it can be difficult to perform preventive tasks. (Strawn, 2018) Fewer and fewer companies are making maintenance part of their competitive strategy. Inadequate maintenance development leads to a decline in an organization's competitiveness. And this has a declining effect on production performance and dependability. In this case, downtime has also increased and production quality may decline. The end-result is unreliability. (Ahuja & Khamba, 2008, p. 710) The valuation of maintenance in a company arises in the management team. It must be understood that maintenance can significantly impact the cost and safety of equipment. Excellent maintenance increases production and profitability. (Idhammar, 2019)

2.1.2 Maintenance classifications and types

According to PSK 7501 standard, maintenance types are divided into two main groups, which are planned maintenance and breakdown maintenance. The classification is based on whether the species cause production interruptions or are planned. In breakdown maintenance, the fault is corrected as required. While in planned maintenance, the work is done according to the planned program at a predetermined time. Planned maintenance includes preventive maintenance, refurbishment and improvement maintenance. Preventive maintenance can be further divided into predetermined maintenance, condition monitoring and condition based planned repairs. (PSK 7501, 2010, p. 5) Figure 2 shows the maintenance types according to PSK 7501 standard.

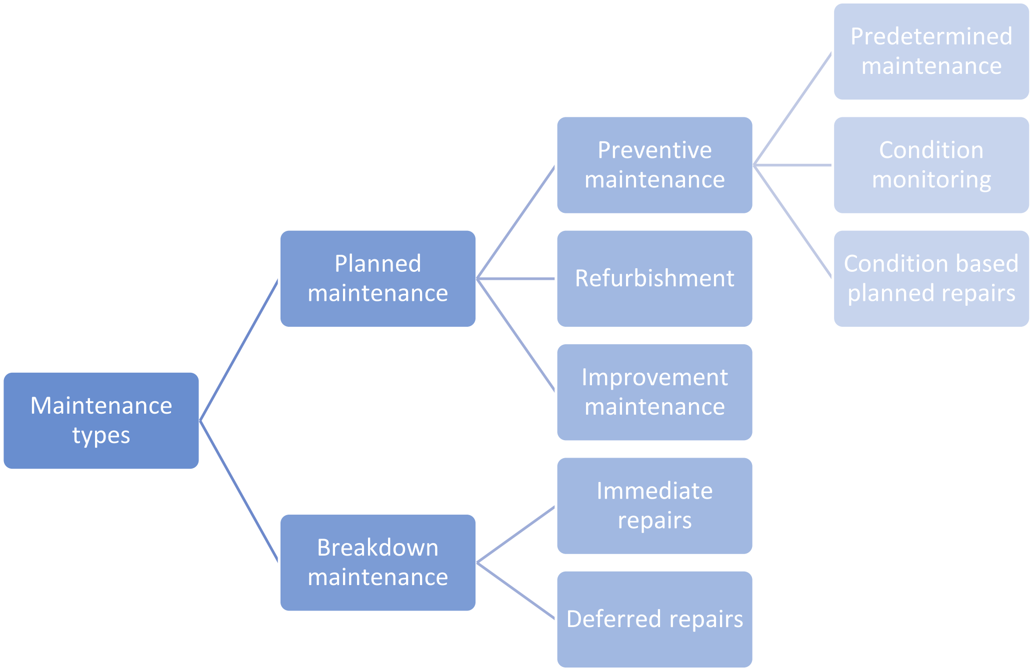

Figure 2. Different maintenance types (PSK 7501, 2010, p. 32).

On the other hand, maintenance types can also be classified in another way according to standard SFS-EN 13306. The standard classifies maintenance types into three main groups, which are corrective maintenance, preventive maintenance and improvement. Preventive maintenance activities take place before the equipment fails, while corrective maintenance activities take place after the equipment fails. Preventive and corrective maintenance are further divided into different sub-functions based on maintenance activities. There are no significant changes of dependability characteristics in preventive and corrective maintenance. However, the purpose of improvement is to improve the dependability of equipment without changing original function. Therefore, improvements can be used to prevent misuse in operation and to avoid failures. (SFS-EN 13306, 2017, p. 58) However, the review of this thesis focuses on the definitions of maintenance types according to PSK 7501 standard.

Breakdown maintenance is the simplest and most easily detectable method of maintenance. In PSK 7501 standard, breakdown maintenance is defined as a failure that prevents equipment from operating as planned. Breakdown maintenance consists of actions aimed to repair the failure. Another maintenance performed during breakdown maintenance caused by a fault is shutdown maintenance. (PSK 7501, 2010, p. 17) Breakdown maintenance is further divided into immediate and deferred repairs. In immediate repair, the equipment is repaired immediately after failure is detected, while in deferred repair, the repair of equipment is deferred to time period that is suitable for production or organization. (PSK 6201, 2011, p. 23) Often failure causes process stopping and requires immediate repair. This type of failure often becomes more expensive for the company, because the failure may cause production losses. Failure costs are often clearly higher than the repairing costs. It is possible to transfer some immediate repairs to the shutdown of production facility, so that no additional production losses have occurred. (Ahamed Mohideen & Ramachandran, 2014, pp. 228-232) Indeed, breakdown maintenance is difficult to forecast, because preparation is often short. By reducing the need for breakdown maintenance, the maintenance costs of production facility can be significantly reduced. In addition, maintenance operations are easier to plan, increasing the productivity and profitability of production facility. A significant way to reduce breakdown maintenance is to increase planned maintenance in maintenance operations. (Tyagi, et al., 2021, p. 440)

In planned maintenance, operations are pre-planned and intended to avoid unpredictable equipment failures such as breakdown maintenance (Mikkonen, 2009, pp. 96-97). The aim of planned maintenance is to create and maintain the most optimal conditions for the operation of equipment and process. Planned maintenance is intended to reduce production and maintenance costs and increase production facility availability. The aim of planned maintenance is also a minimum amount of the defects and failures of equipment. (Jasiulewicz-Kaczmarek, 2016, p. 675) Planned maintenance often requires disciplined maintenance planning. In the planning process, a wide range of information must be collected from different data tracking systems to perform maintenance functions efficiently. The planning process also requires problem solving as well as careful scheduling. Listed below are key factors for effective planned maintenance and completing:

- Support maintenance in autonomous direction
- Planned maintenance
    - Extending the lifetime of equipment
    - Knowledge of using various maintenance actions
    - Stabilization of failures (MTBF)
    - Utilization of predictive maintenance techniques
- Determining the structure of planned maintenance
- Management of lubrication techniques
- Spare parts management
- Reduction of maintenance costs
- Maintaining and improving maintenance skills
- Successful use of predictive maintenance techniques. (Jasiulewicz-Kaczmarek, 2016, pp. 675-676)

2.1.3 Different maintenance strategies

Maintenance strategy is defined when planning maintenance activities. Maintenance strategy refers to an operating model that aims to achieve objectives, which set for maintenance. Maintenance strategy defines necessary maintenance facilities and equipment, human resources, management of equipment technical information and maintenance material management. (PSK 6201, 2011, p. 13) Maintenance strategy of equipment may be based on reactive, predictive or preventive maintenance to failure situations. However, in more advanced maintenance strategies combine the components of different maintenance strategies and apply them to larger entities. In addition, in more advanced maintenance strategies, organizations can further evaluate and develop the condition of equipment. And more advanced maintenance strategies using the information produced, guided by chosen strategy for organization. (Manzini, et al., 2010, pp. 71-72) More advanced maintenance aims to the continuous development and modification of maintenance operations.

Continuous development is achieved by constantly enquiring issues related to maintenance, operating models and considering their suitability for production facility. In addition, deep-rooted habits must be enquired. (Fedele, 2011, p. 12) Such more advanced maintenance strategies include reliability cantered maintenance, total productive maintenance and asset management. (Manzini, et al., 2010, pp. 71-72)

Total productive maintenance is a maintenance philosophy from Japan industry. TPM combines several maintenance strategies and aims to improve production availability, product quality and operative safety. Thus, if TPM strategy succeeds, it can be improved equipment productivity, reduced quality deviations and extended equipment lifetime. (Fedele, 2011, pp. 12-13) The benefits of TPM strategy include reduced unplanned maintenance actions, due to careful planning and scheduling. Other benefits include reduced equipment failures, lower manufacturing costs and improved workplace safety (6S). (Hardt, et al., 2021, p. 2)

The objective of asset management is to keep production assets in a condition that achieves business objectives at the lowest possible cost (Performance Culture). In order to achieve objectives, the whole asset entities must be taken into account from business, production and maintenance perspectives. In addition, all aspects related to the management of production assets must be in order, such as the management of daily actions, the management of preventive maintenance, the effective cooperation between various stakeholders of the company and the operation of equipment reliably. (Järviö, 2007, pp. 93-94) A five-stage pyramid developed by SAMI (Strategic Asset Management Inc.) can be used to manage production assets, with each having its own requirements in terms of maintenance management and functionality. In the pyramid, the objective is to eventually reach the top stage, i.e. performance culture. The pyramid illustrating maintenance stages is shown in Figure 3.

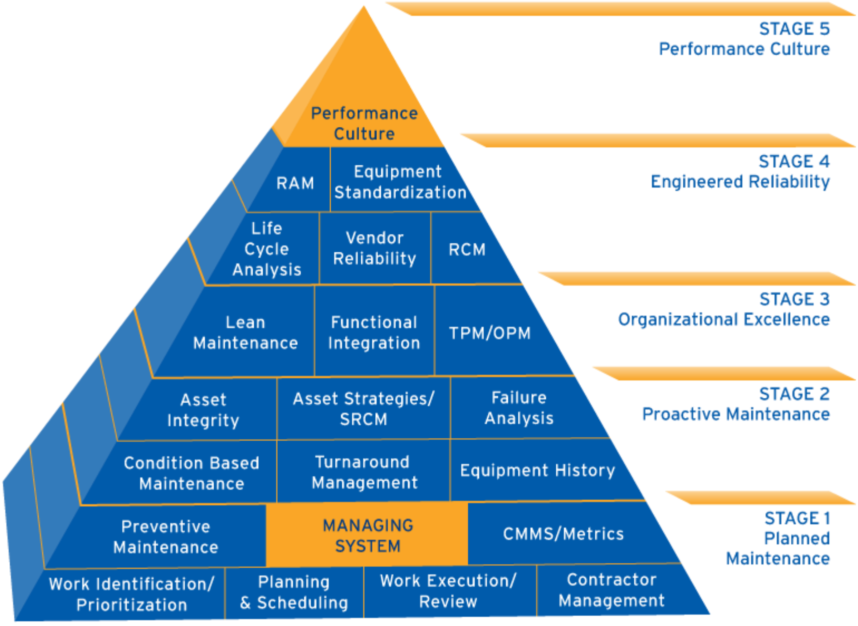

Figure 3. The maintenance stages in industrial organization (Strategic Asset Management Inc., 2021).

The strategy philosophy of this thesis has been chosen as reliability centered maintenance. RCM maintenance strategy is discussed in more detail the below chapter.

2.1.4 Reliability centered maintenance – phases, benefits and objectives

RCM is an abbreviation of the words Reliability Centered Maintenance. Roots of the method are in the needs of the aircraft industry, which has been developing a systematic method to increase aircraft operational reliability. Reliability centered maintenance is one of the most important tools in maintenance planning. The method is commonly used as a systematic method in the maintenance planning process. RCM consists actual maintenance activities, planning and development of the equipment from the maintainability and reliability perspective. (Kotkansalo, et al., 2017, p. 25) RCM is a task-oriented maintenance strategy. The objective is to direct resources to maintenance of the most critical equipment. In RCM, equipment are typically organised into three criticality categories: A (most critical), B (medium critical) and C (least critical). Typically, there are 20-30 percent of A-cases, 30-40 percent of B-cases and the rest are C-cases. The objective is to plan maintenance instructions for A-cases, which identifies the most critical failure modes based on failure mode and effects analysis. For each failure mode, predictive, preventive and improvement action is assigned. This reduces risk to a more acceptable level. Predictive actions are related to condition monitoring. Preventive actions are intended to prevent failure, this includes, for example the replacement of wearing parts and lubrication. Improvement action may be, for example modernization. (Kotkansalo, et al., 2017, p. 26)

Reliability centered maintenance has many objectives that should be considered. Listed below are main objectives of the method:

- Equipment prioritization. Equipment prioritization focuses maintenance on equipment that needs it most. Prioritization factors include cost, safety, environmental requirements and quality.
- Determine the mechanisms of equipment failure. Be able to choose the correct and most effective maintenance method for equipment.
- Passive equipment under maintenance. Passive limit and safety equipment during the process are placed under maintenance.
- Failure anticipation. For equipment for which no effective method of preventive maintenance can be found, ready-made operating instructions should be drawn up for possible failures.
- User maintenance. Operating employees of the equipment actively monitor the operation of critical components. (Mikkonen, 2009, p. 75)

Reliability centered maintenance also aims to determine the most cost-effective and suitable maintenance tasks for each equipment. The aim is to minimize the impact of risks on equipment operation. As well as ensuring the continuous functionality of equipment as economically as possible. RCM also aims to refurbish the condition of equipment to a pre-failure level and to ensure with careful planning that no failures occur in the future. RCM can be used to effectively account for equipment availability and safety. However, at a reasonable maintenance cost. RCM strategy benefits also include increased facility availability, a foundation for preventive maintenance documentation, efficient preventive maintenance planning and improved spare parts manageability. RCM also reduces need for breakdown maintenance. (Duffuaa & Raouf, 2015, pp. 247-248) The objective and at the same time benefits of RCM is to improve the reliability of equipment. RCM also enhances equipment performance and efficiency and, of course, is a cost-effective maintenance strategy. (Azid, et al., 2019, p. 7)

The phases of reliability centered maintenance are often described in a seven-step process. The seven-step process is based on Moubray's Reliability Centered Maintenance -book. Seven-step RCM process is shown in Figure 4 below. (Manzini, et al., 2010, pp. 72-73)

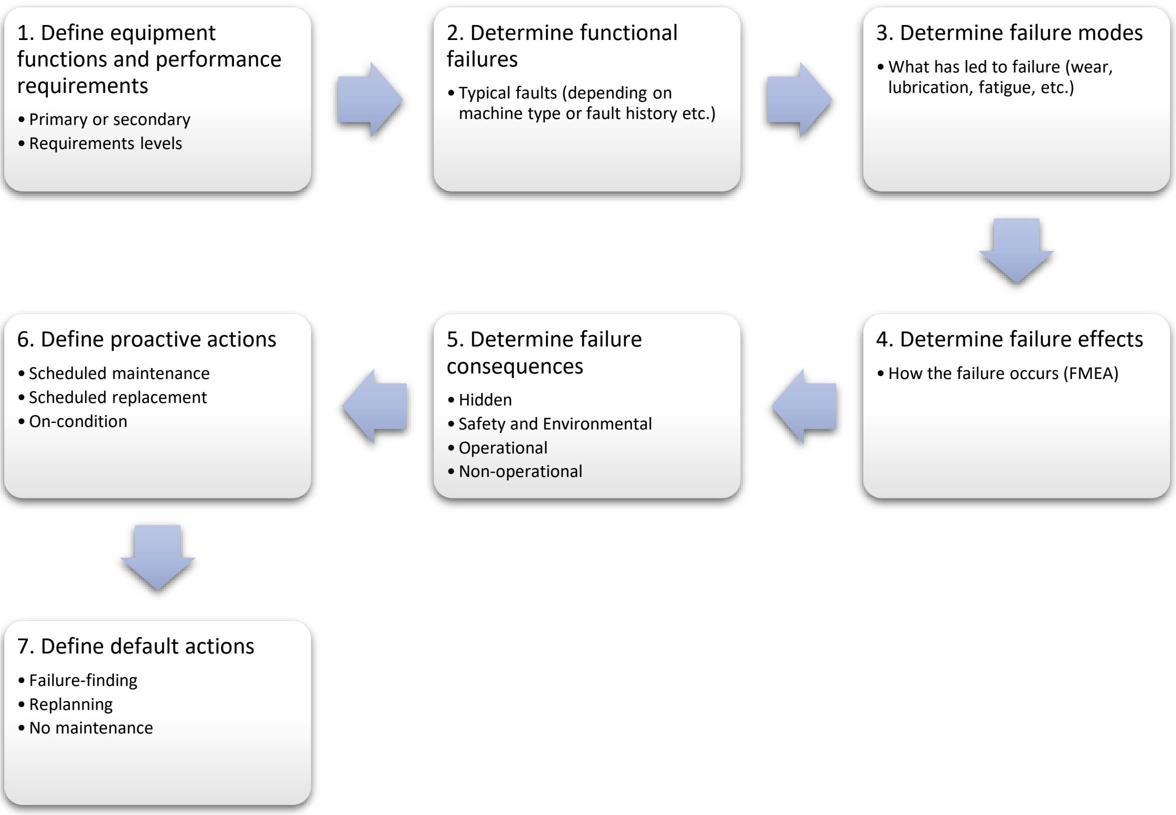

Figure 4. Seven-step process of reliability centered maintenance (Manzini, et al., 2010, pp. 72-73)

The first four steps of RCM process are used to determine where maintenance activities should be focused, and the fifth is to prioritize equipment and its priorities. The last two steps identify the most effective operating actions to best manage failures and the effects of failures. (Järviö & Lehtiö, 2017, p. 164) In a modern RCM process, steps of the process are slightly different from the original. Listed below are steps of modern RCM methodology:

1. Selecting a system and collecting information
2. Defining system limitations
3. Description of the system and definition of the different functions of the system
4. Functions and failures
5. Failure mode and effects analysis (FMEA)
6. Logic decision, tree analysis (LTA)
7. Select the task to be implemented. (Duffuaa & Raouf, 2015, p. 249)

2.1.5 Preventive maintenance and its planning

Preventive maintenance refers to activities that are planned to be performed in advance. Preventive maintenance aims to prevent equipment failures caused by known causes. Preventive maintenance can be scheduled based on time, usage or condition of equipment. Primarily, maintenance activities are carried out preventive maintenance and to avoid breakdown maintenance. (Duffuaa & Raouf, 2015, p. 59) Reasons, why want to use preventive maintenance in comparison with breakdown maintenance are the following points:

- Premature failures can be reduced through efficient lubrication, cleaning and inspections.

- However, if equipment failure cannot be prevented, regular inspections and measurements can reduce the severity of the failure and impact other aspects of the process (safety, environment, production capacity).
- Product quality and equipment vibration should be monitored in real-time to detect incoming failures in time.
- In case of equipment failure, the direct and indirect costs increase compared with preventive maintenance costs. Repairs quality also often deteriorates under production pressure. (Duffuaa & Raouf, 2015, p. 59)

Objectives of preventive maintenance include reducing failures of equipment. Including reducing the amount and duration of failures. In addition to reducing additional shutdown. Reduction of abnormalities to ensure stabilization of equipment conditions. Reducing costs, especially scrap and component costs. (Hardt, et al., 2021, p. 5) Mechanical maintenance activities are generally not subject to legislative directives, but there are exceptions. However, preventative maintenance should include standardized working methods. Objective is to keep the functions of equipment running. Occasionally, situations get up that are indirectly related to other activities of production facility, such as:

- Lack of human capacity leads to ineffective preventive maintenance planning.
- Lack of funds leads to inefficient replacement of components.
- Lack of time leads to inefficient work planning.
- Unorganized work leads to inefficient work management. (Hardt, et al., 2021, p. 5)

When planning preventive maintenance operations, the need for preventive maintenance should be determined separately for each situation. Preventive maintenance is economically viable and justified if it can be demonstrated that the benefits are greater than preventive maintenance costs. Comprehensive equipment information and its failure history make it easy to make preventive maintenance plans. Failure history can be used to determine how single equipment fails and whether it has a recurrence over time. When forecasting failures based on historical data, the data must be reliable and freely available. Based on incorrect information, economically unprofitable preventive maintenance is often created. (Järviö & Lehtiö, 2017, pp. 103-104)

Preventive maintenance plans are used to manage periodic maintenance. Instructions of maintenance plans are often based on equipment criticality, regulatory intervals, experience failure intervals and equipment manufacturer recommendations. Preventive maintenance instruction defines all necessary information about maintenance action of the equipment. With the help of carefully planned maintenance instruction, even a maintenance employee who is already unfamiliar with the equipment would be able to carry out maintenance action. However, employees must have appropriate qualifications for the work. Instructions are usually divided into running time and shutdown actions for preventive maintenance. Instructions must also show periodicity of the work, necessary resources, spare parts and instructions for the work. Preventive maintenance instructions are often based on equipment manufacturer’s maintenance instructions. However, specific equipment may require maintenance slightly differently from the manufacturer's instructions due to access to the equipment being weak or an alternative maintenance plan being created. Alternative maintenance plans are often referred to as experience-based maintenance plans. However, creating an experience-based maintenance plan required excellent knowledge of the equipment and how it works. (Heinonkoski, 2013) Preventive maintenance instructions should include equipment ID and name, name of the preventive maintenance work, a brief work description, intervals, the first date of maintenance, additional maintenance information and references to technical documents and spare parts, if relevant. (Caverion, 2021)

Problems with preventative maintenance plans are often their unnecessary scope or, correspondingly, they are too compact. In both cases, the need for preventive maintenance decreases and the amount of corrective maintenance increases accordingly. Therefore, the problem with preventative maintenance plans is optimizing them. (Caverion, 2021) Listed below are options for optimizing preventive maintenance plans:

- Take advantage of the manufacturer's instructions and regulatory requirements.
- Prioritize equipment using criticality classification.
- Utilize machine learning technologies to plan preventive maintenance actions. (Caverion, 2021)

One of the problems of planning preventive maintenance is scheduling it and determining correct maintenance intervals. Preventive maintenance actions can be scheduled in several ways depending on equipment to be maintained. Often preventive maintenance actions are scheduled with too long cycles, which result in decreasing performance of equipment. Preventive maintenance actions should also be divided into shorter cycles and more frequent tasks. This will guarantee the availability and reliable operation of equipment in the future. (Minho, et al., 2021, pp. 104-105)

Some mathematical model is commonly used to determine preventive maintenance intervals. Determining PM intervals can also be done based on experience or failure information, but in this case, determining the correct PM intervals may fail. A commonly used mathematical equation for calculating PM intervals is shown below: (Järviö & Lehtiö, 2017, pp. 100-102)

$$T(interval) = 2 * unavailability * MTBF \qquad (1)$$

Equation 1 can be used to calculate PM intervals for several different time variables, but the most common are PM intervals defined in weeks or months. Equipment or department determines the unavailability value. Unavailability can be, for example, the percentage of disturbance allowed by the department. In equation, the unavailability value is calculated as numerical, 0 to 1. Mean time between failure, i.e. MTBF, is also determined for each equipment or department. And equation indicates MTBF value in time format where calculated PM interval (T) is to be determined. (Järviö & Lehtiö, 2017, pp. 100-102)

2.1.6 Machine learning to support preventive maintenance planning

Industry evolves and becomes “smarter” by utilizing machine learning in operations. Machine learning (ML) collects knowledge and processes it. Machine learning uses information it receives and tries to automate specific processes with the help of information. Machine learning utilizes big data as well as industrial internet of things (IIoT). (Nacchia, et al., 2021, p. 2) Machine learning is an excellent method as a supportive activity in preventive maintenance planning. Machine learning can be used to optimize the need for preventive maintenance of equipment. As well as machine learning, transition to efficient predictive maintenance (PdM) is simplified. Utilization of machine learning in preventive maintenance planning consists of three important main phases, described as follows:

1. Initially should collect and process the obtained data from the equipment. Data processing includes cleaning and filtering data and optimizing and normalizing features and dimensions.
2. Using machine learning, based on the data collected, the amount of need for maintenance required by equipment is predicted.
3. The data obtained will be analysed, which will help to plan the need for preventive maintenance. Planning takes into account, among other things, maintenance history of the equipment, maintenance cycle and duration, and optimizes the need for maintenance resources. (Li, et al., 2020, pp. 548-549)

Development of machine learning has been quick in recent years and more and more industrial companies are utilizing it in their various operations. Sensor technology, in particular, has evolved as a result of Industry 4.0, providing important information on the condition and availability of equipment. Based on information provided by sensors, preventive maintenance can be developed and operating models can be optimized. Often, early failures that are difficult for a human to detect can also be better detected based on the data. So that failure does not have time to occur. (Ochella, et al., 2021, pp. 1-2) However, the data provided by sensors should not be fully trusted, as it may be incorrect or contradictory. So the data should be observed critically. (Giacotto, et al., 2021, p. 3)

2.1.7 Cost-effective preventive maintenance planning

Total maintenance costs consists of preventive and corrective maintenance costs, as illustrated in Figure 5. An optimized preventive maintenance strategy can reduce the cost of corrective maintenance. In this way, the optimal amount of maintenance is achieved compared to costs incurred. The optimal zone is difficult to determine, but is achieved when both costs are in balance. (An, et al., 2018, p. 710)

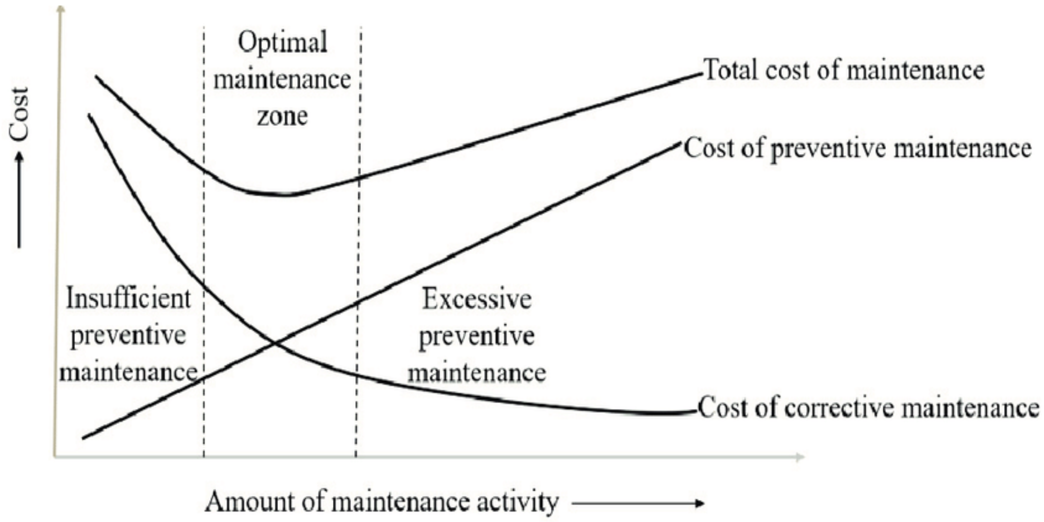

Figure 5. Optimal maintenance costs taking into account the cost of preventive and corrective maintenance (An, et al., 2018, p. 710).

Cost-effective preventive maintenance planning analyses capital costs and economic benefits through preventive maintenance, such as increased availability. Cost planning is therefore very important in cost-effective preventive maintenance. Preventive maintenance costs include repair, replacement, spare parts, tools and labour costs. Also taking into account shutdown costs. Financial losses to be avoided through preventive maintenance include high costs due to equipment failures and production losses. (Basri, et al., 2017, pp.

121-122) The five steps optimization process can be used to achieve benefits that minimize lifecycle costs. Steps are as follows and should be considered at planning phase:

1. Identification of critical functions, elements and areas
2. Understanding failure modes and their effects
3. Evaluation of current maintenance activities
4. Utilizes predictive maintenance technology
5. Development of maintenance in accordance with best practices. (An, et al., 2018, pp. 710-711)

It has been shown that up to 60 percent of maintenance costs could be prevented by optimization. In practice, a 20-30 percent reduction in costs can be achieved easily. Breakdown maintenance is estimated to require three to four times more labour and costs than preventive maintenance. Maintenance costs can be challenging to determine because often costs are hidden. For example, it is difficult to calculate the cost for a production shutdown or a late schedule. Lack of documentation of actions also makes it difficult to perceive costs. If it is not known exactly what is being done, it is difficult to determine the exact cost. (Strawn, 2018)

2.1.8 Failure of equipment

An equipment fault means that system is in a condition that it cannot perform the required function. Usually, the fault is due to a failure, but sometimes fault exists before failure. On the other hand, failure means that the ability of the system to produce desired function is lost. Failure is a happening and fault is a state. The one of important term is failure mode, which is sometimes confused with failure. Failure mode means a happening that prevents system performing desired function. (SFS-EN 13306, 2017, pp. 26-31)

Failures of equipment are simple to determine in theory, but failures are often difficult to verify in real life. Failure time due to failures of equipment often consists of random variables, and exact failure time caused by a failure is difficult to determine. In addition, failure times of different failures and equipment differ significantly, which increases the difficulty of verifying them. (Birolini, 2017, p. 3) Failures of equipment can be classified into four different states, which are:

1. Mode that refers to a sign of failure (local effect). For example, creep, fatigue, brittle fracture and buckling.
2. Cause that refers the cause of failure (internal and external).
3. Effect that reflects the effect of failure on equipment itself, other equipment or a larger scale process.
4. Mechanism, i.e. the failure mechanism that consequences failure (physical, chemical or other processes). (Birolini, 2017, pp. 3-4)

2.1.9 Failure modes based on time

Failure and life cycle of equipment have been thought to follow bathtub failure mode shown in Figure 6, where horizontal axis shows timeline and vertical axis number of failures. These can be separate three different steps; early failures, stable failure rate and failures due to wear and ageing. (Birolini, 2017, pp. 6-7) The steps are marked with numbers in Figure 6.

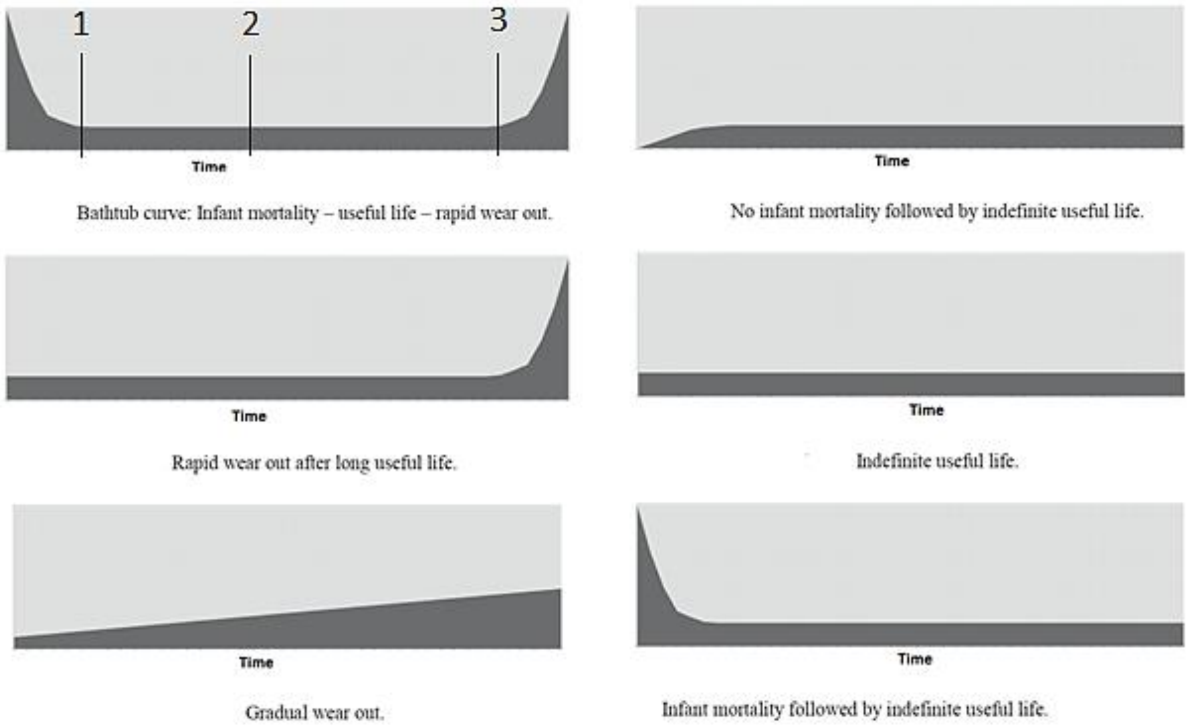

Figure 6. Different failure modes as a function of time (Baglee & Jantunen, 2014, pp. 88-89).

All failure modes follow the steps of bathtub mode with slight differences. In failure modes, failure interval of bathtub and infant mortality is higher at the beginning of the life cycle and the probability of failure of these decreases rapidly. However, failures at the first step are occasional and are often due to material weakness, installation defects or production process. In no infant mortality failure mode, failure is less probable at the first stage. At the second stage, the failure interval of all other failure modes except gradual wear out has been standardized. The probability of gradual wear out failure increases linearly. At the third stage, the failure accelerates, as with failure modes like rapid wear out and bathtub. (Birolini, 2017, pp. 6-7)

Also, failure of equipment is quite often described by the P-F curve. P-F curve is utilized in several different sectors of industry. In it, P (potential failure) means the point at which the failure begins and F (functional failure) is the moment when equipment or part of it can no longer perform intended function, i.e. is damaged. Typically, markings are placed at different points on this curve as to what phase a failure can be detected with the help of different maintenance types. (Zofka, 2020, pp. 119-120) Figure 7 shows P-F curve and its different phases.

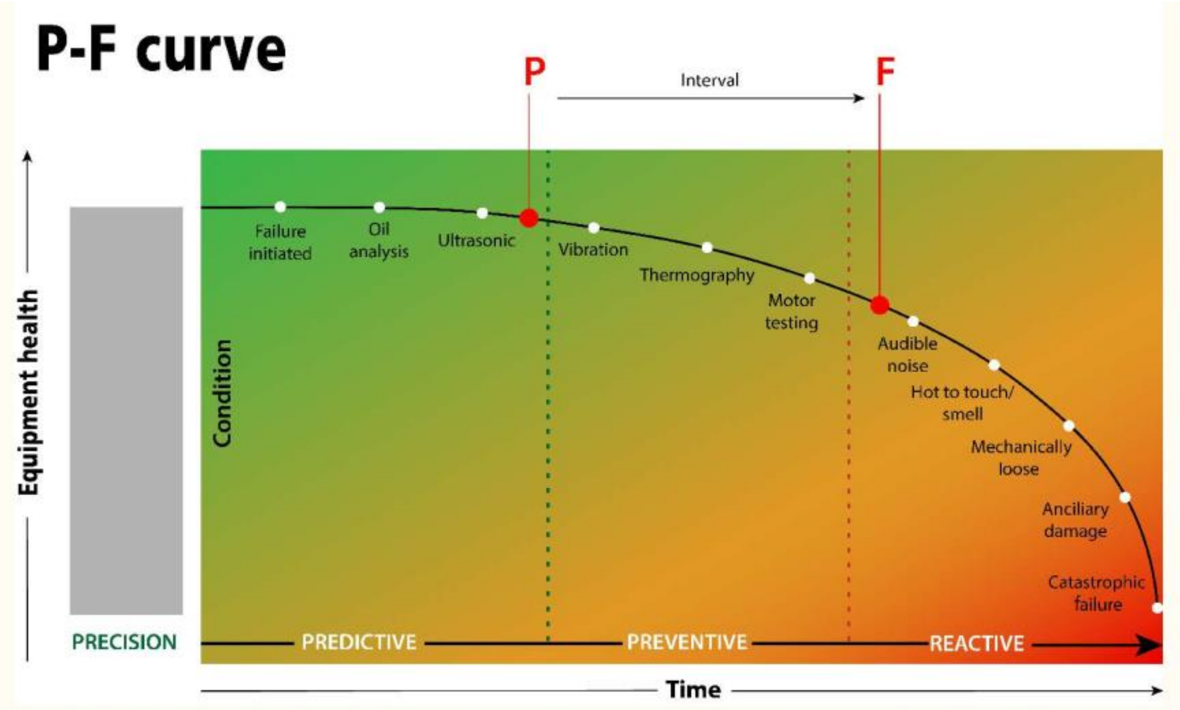

Figure 7. P-F curve and its various phases (predictive, preventive and reactive). (Clark, 2019, p. 35).

Before P point, i.e. the onset of failure, equipment is subjected to oil analysis and ultrasonic and visual inspections. These are predictive actions. Even before the final failure of equipment, among other things, vibration and temperature measurements are performed to prevent further failure. These are preventive actions. When equipment fails, often hear an unusual noise from equipment, temperature will rise and equipment will start smoking. At this point, failure has already occurred. (Clark, 2019, p. 35)

2.1.10 Causes of failure

In total productive maintenance philosophy, failures of equipment have been thoroughly considered throughout history, and the philosophy states that there are five main causes of equipment failures. These main causes are listed below:

1. Equipment is not used correctly and failures that start are not responded to in a timely manner.
2. The signs of fault are misinterpreted and necessary maintenance is carried out incorrectly.
3. Weakening due to ageing of equipment is not detected in time or repaired.
4. The operating conditions of equipment are not optimal. Uncleanness often causes equipment to overheat or change movements.
5. Equipment design process has failed or equipment is not suitable for that process. (Järviö & Lehtiö, 2017, p. 81)

Determining the signs of fault is usually complicated and may be misinterpreted. In many cases, onset signs are considered to be only age-related phenomena. They are often not considered serious enough to be worth responding to. Inspections may also be too general and also not want to go to unclean and hard-to-reach equipment. Hidden failures cause many equipment failures. Hidden failures may appear normal, but are often the main cause of equipment failure. Hidden failures can be divided into physical and psychological failures. Physical hidden failures can be caused by inadequate inspections, poor failure analysis or equipment that are difficult to inspect. Psychological hidden failures due to faults being knowingly disregarded even if they are identified. Problems are underestimated and the problem is not responded to well enough. In addition to these, maintenance activities may be mainly focused on making repairs, in which case no effort has been made to find out the signs of failures. Taking into account the below points, the reliability of equipment can be improved. The trouble-free operation of equipment is achieved by being able to perform the following five operations, continuously and carefully:

1. Maintain equipment operation (including cleaning, lubrication, joint tightening and alignment).
2. Observe intended use and conditions of equipment.
3. Make sure that the functions of equipment corresponding to the functions of the new corresponding equipment.
4. Improve design errors in equipment.
5. Develop operation and maintenance skills. (Järviö & Lehtiö, 2017, pp. 81-83)

2.2 Risk analysis methods for maintenance

Risk analysis methods for maintenance are used to bring new methods and development ideas for the development of preventive maintenance. The section introduces the methods used in the thesis and their theory. More detailed results of the risk analysis methods are in the results and analysis section.

There are several different methods that have been developed for risk and reliability analysis. The main purpose of risk analysis is to determine objects, nature, probability of their occurrence and extent of their effects. Risk analysis tools are used when a deeper understanding of different potential risks is needed, in the risk management process and in making decisions to minimize risks. Risks can be related to environment, safety or production. (SFS-EN IEC 31010, 2019, pp. 7-10) A few commonly used risk analysis methods are presented below, of which failure mode and effects analysis and criticality classification of equipment method according to PSK 6800 standard have been applied in this thesis.

2.2.1 Criticality classification of equipment in industry (PSK 6800)

Criticality classification of equipment –standard defines the criticality of equipment as a property that reflects the magnitude of the risk associated with equipment. Equipment is classified as critical if associated risks are not at an acceptable level. Risk factors include injury, significant material damage, loss of production, or other risks. Criticality classification of equipment is mainly used to review the criticality of production processes. The method seeks to obtain economic benefits. The method examines economic effects in terms of loss of production, quality costs and repair or consequential costs. Repair costs are incurred when equipment fails and consequential costs are incurred if a failure of equipment results in damage to equipment or failure of another equipment. From a maintenance perspective, method is often used as one of the tools in maintenance planning. Method can also be utilized in equipment procurement stages, where the critical equipment´s characteristics, quality level and acceptance criteria are determined. (PSK 6800, 2008, pp. 2-4)

Criticality classification of equipment consists of a seven-step assessment, which is performed on equipment or component specific basis. Below are the steps according to criticality classification:

1. Define and limit scope of the review.
2. Determine the weight factor of production loss.
3. Evaluate other suitable weight factors for equipment.
4. List other equipment or components to be analysed.
5. Determine coefficients to be used for equipment under consideration.
6. Calculate criticality index and sub-indices of equipment.
7. Arrange equipment in the order of criticality index. (PSK 6800, 2008, p. 3)

The magnitude of equipment criticality index is affected by many factors. According to PSK 6800 standard, weighting factor, time between failures and various multipliers effect the magnitude of the criticality index. The multipliers are determined by their selection criteria. The standard also divides equipment criticalities into sub-indices; safety, environment, production loss, quality cost and repair or consequential cost. Table 1 below shows weighting factors, multipliers and selection criteria for equipment. (PSK 6800, 2008, pp. 7-8)

Table 1. Weighting factors, multipliers and selection criteria for equipment (PSK 6800, 2008, p. 7)

Object	Weighting factor [W]	Time between failures [p]	Multiplier [M]	Selection criteria
Safety and environmental impacts	Safety risks $W_s = 30$	1 = Long time between failures, eg. over 5 years 2 = Quite long time between failures, eg. 2 to 5 years 4 = Quite short time between failures, eg. 0.5 to 2 years 8 = Short time between failures, eg. 0 to 0.5 years	$M_s = 0$	No safety risk
			$M_s = 2$	Minor safety risk
			$M_s = 4$	Moderate safety risk
			$M_s = 8$	Major safety risk
			$M_s = 16$	Serious safety risk
	Environmental risks $W_e = 20$		$M_e = 0$	No environmental risk
			$M_e = 2$	Minor environmental risk
			$M_e = 4$	Moderate environmental risk
			$M_e = 8$	Major environmental risk
			$M_e = 16$	Serious environmental risk
Production impacts	Production loss $W_p = 0…100$		$M_p = 0$	Non-operation of equipment has no impact on the sub-process or department
			$M_p = 1$	Non-operation of equipment stops the sub-process or department momentarily (eg, ≤3 h)
			$M_p = 2$	Non-operation of equipment stops the sub-process or department for a short time (eg. ≤10 h)
			$M_p = 3$	Non-operation of equipment stops the sub-process or department for a considerable time (eg. 10 to 24 h)
			$M_p = 4$	Non-operation of equipment stops the sub-process or department for a long time (eg. >24 h)
	Quality cost $W_q = 30$		$M_q = 0$	Non-operation of equipment does not cause quality costs to the end product.
			$M_q = 1$	Non-operation of equipment causes quality costs on the end product equivalent to a momentary production loss (eg. ≤1 h)
			$M_q = 2$	Non-operation of equipment causes quality costs on the end product equivalent to a short-term production loss (eg. ≤3 h)
			$M_q = 3$	Non-operation of equipment causes quality costs on the end product equivalent to a major production loss (eg. 3 to 8 h)
			$M_q = 4$	Non-operation of equipment causes quality costs on the end product equivalent to a long-term production loss (eg. >8 h)
Repair or consequential costs	Repair or consequential cost $W_r = 20$		$M_r = 0$	Repair or consequential costs are not significant in relation to other losses.
			$M_r = 1$	Minor repair or consequential costs equivalent to a momentary production loss (eg. ≤2 h)
			$M_r = 2$	Medium repair or consequential costs equivalent to a short-term production loss (eg. ≤10 h)
			$M_r = 3$	High repair or consequential costs equivalent to a major production loss (eg. 10 to 24 h)
			$M_r = 4$	High repair or consequential costs equivalent to a long-term production loss (eg. >24 h)

[1)] Values are informative.

$$K = p * (W_s * M_s + W_e * M_e + W_p * M_p + W_q * M_q + W_r * M_r) \quad (2)$$

Equation 2 is used to find the criticality index of equipment. Equation consists of different multipliers in Table 1 and their numerical values. (PSK 6800, 2008, p. 8) Appendices 1 and 2 contains an example of an excel template, which can be used for calculation.

2.2.2 Failure mode and effects analysis (FMEA)

Failure mode and effects analysis (FMEA) and reliability centered maintenance (RCM) are very important philosophies in preventive maintenance actions. FMEA is used to try to determine all possible failures in equipment and their different failure modes. (Braaksma, et al., 2012, p. 1055) FMEA is also used to identify potential failures and eliminate them. FMEA is used to improve equipment reliability and safety and help manage risks. FMEA takes into account various risk factors, which are occurrence, severity and detection. The objective of FMEA is to prioritize equipment failure modes so that limited resources can be targeted at risk equipment. (Liu, et al., 2013, p. 829) FMEA has many advantages as to why it should be used as a risk analysis method. Listed below are the main benefits to be achieved with FMEA:

- Be aware of risks to reliability by documenting and communicating the matter further.
- Helps reduce the potential for major failures that could interfere with other activities.
- Optimize required preventive maintenance actions for different equipment. (Ben-Daya, 2009, p. 76)

Typical phases in FMEA process are initially to determine selected equipment or component. The functions of equipment are then determined in order to determine failure of equipment and failure modes. The effects of failure locally and the rest of the process are then analysed.

FMEA is used to determine necessary maintenance actions and to prevent reappearance of failure. (Braaksma, et al., 2012, p. 1056) Figure 8 below shows the phases of FMEA process.

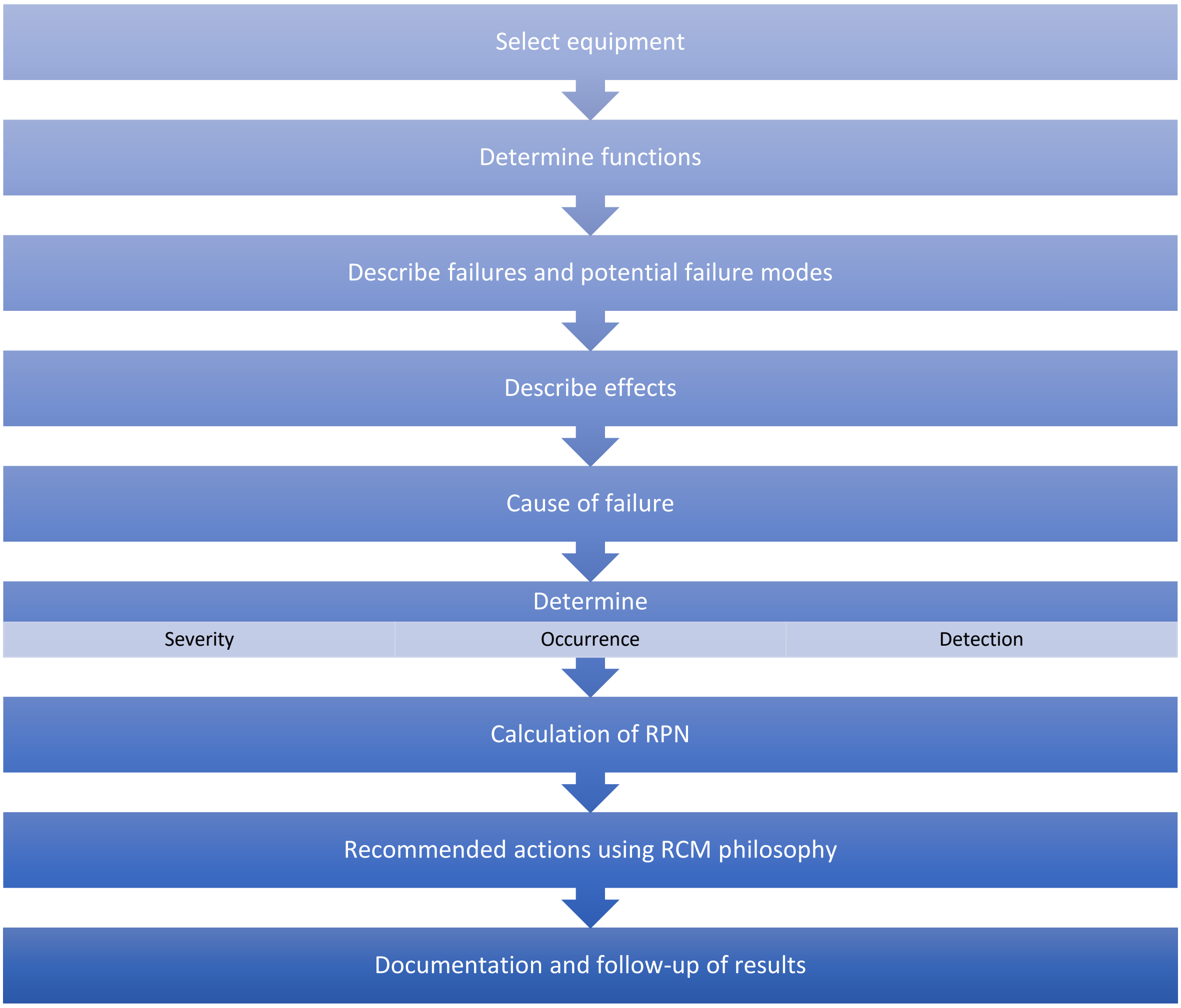

Figure 8. Phases of FMEA and as part of RCM process (Braaksma, et al., 2012, p. 1056; Filz, et al., 2020, p. 3).

The end result of risk analysis for failure modes is calculated Risk Priority Number (RPN) to describe the significance of failure mode. The risk priority number is formed by the result of severities, occurrence and detections. Each is evaluated by numbers 1 to 10. The higher risk priority number, the more significant failure mode. Risk analysis provides failure modes for which curative actions should be found primarily to reduce likelihood, consequences or perceptibility of failure mode. (Balaraju, et al., 2020, pp. 835-836) The method for calculating risk priority number is:

$$RPN = Severity\ (S) * Occurrence\ (O) * Detect\ (D) \tag{3}$$

Severity, occurrence and detect coefficients used in Equation 3 are based on definitions presented in the scientific article for each coefficient separately. (Wannawiset & Tangjitsitcharoen, 2019, pp. 3-4) The thesis utilizes coefficient defined by the article.

2.3 Databases of Ovako

Many databases used by Ovako are utilized in the thesis as a method. The most important database to be utilized is the maintenance management system of Ovako (Pinja Novi), where actual preventive maintenance instructions and their modification take place. More details on the maintenance management system and its structure are in the sections below. Another important database is Promas system. Promas registers, among other things, equipment failure information. These databases are utilized in the thesis in collecting and processing data.

2.3.1 Modern maintenance management system and its structure

The maintenance management system is used to manage the operational control of maintenance and material flows. Maintenance management system is connected to the other information systems of production mill. The end-user of maintenance management system includes, among other things, its own maintenance employees, supervisors, managers, production employees and external maintenance employees. Today, maintenance employees play a key role in generating new information for maintenance management system. Maintenance management system is often abbreviated as CMMS, which comes from the words Computerised Maintenance Management System. Another abbreviation for maintenance management system is EAM, which comes from the words Enterprise Asset Management System. (Mikkonen, 2009, p. 116)

There are different maintenance management systems depending on suppliers, and they are often implemented in different ways. Many maintenance management systems have versatile expansion options. However, maintenance management systems with the same basic features include the same maintenance functions. (Mikkonen, 2009, pp. 116-119) CMMS can be either web-based, hosted by the company that sold the product on an external server, or LAN-based, i.e. organization that purchasing the software hosts the product on its server (Howell & Alshakhshir, 2017, p. 114). Maintenance management systems have evolved considerably in recent decades. The current Industry 4.0 concept has made maintenance management systems increasingly autonomous. Digitization is a strong trend globally in the industry. A modern maintenance management system has also been desired to match the industry development. Modern maintenance management system is abbreviated CMMIS, which comes from the words Computerised Maintenance Management Information System. Figure 9 below shows the different modules of CMMIS. (Hardt, et al., 2021, pp. 5-6)

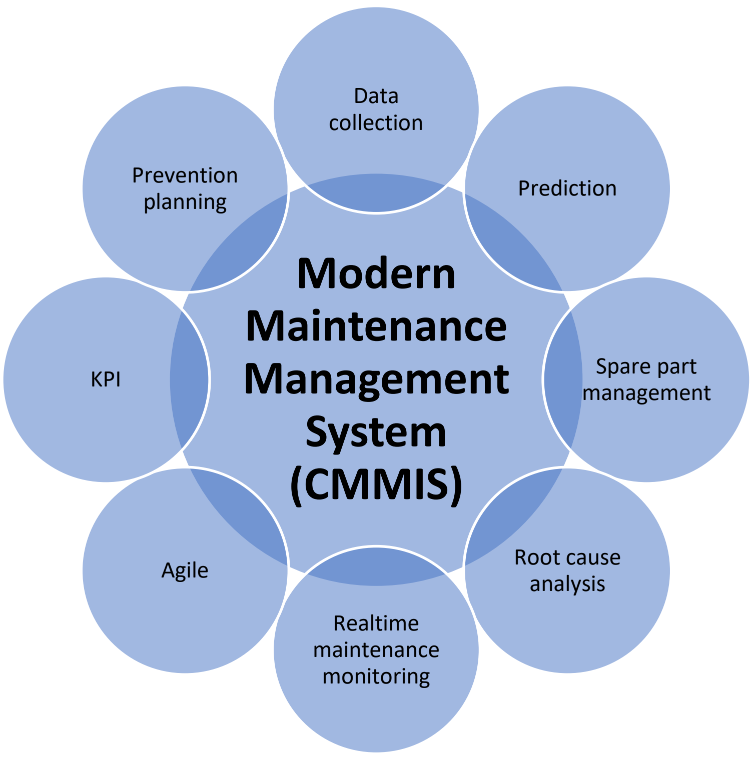

Figure 9. Modules of computerised maintenance management information system. (Hardt, et al., 2021, p. 6)

Modern maintenance management system should thus include the above-mentioned modules in order to meet the needs of Industry 4.0. CMMIS includes data collection and its conversion for maintenance purposes. CMMIS data is collected through sensors installed in equipment and other automated systems. The data can be utilized in preventive maintenance planning and spare parts management. Data can also be used to detect abnormalities in production equipment, visualize information to users, root cause analysis and determine KPI information. Based on this information, decisions on further action will be made. Data material is also used to create reports for management team. Indeed, modern maintenance management system meets all the requirements for efficient maintenance and supports the Industry 4.0 targets. (Hardt, et al., 2021, p. 6)

Modern maintenance management system also enhances the impact of preventive maintenance. CMMIS can be used to schedule preventive maintenance activities. In addition, CMMIS provides work orders, inventory management, maintenance plans, reports and other functions related to preventive maintenance. CMMIS can significantly reduce maintenance costs and increase productivity. CMMIS also extends the life cycle of a production facility at minimum cost. Other benefits of a modern maintenance management system include its ease of use, customizability of maintenance plans, minimization of shutdown and availability of maintenance data and history. (Howell & Alshakhshir, 2017, pp. 114-115)

2.3.2 Pinja Novi – maintenance management system

Pinja Novi is a maintenance management system in use at Ovako. Novi was commissioned at the mill in November 2021. The previous maintenance management system at the mill was Oracle Powermaint. Powermaint had been in operation at the mill since 1998. However, new maintenance management system Novi is more modern and user-friendly than its predecessor Powermaint and has better customizability.

Maintenance management system plays an important role in this thesis. The current preventive maintenance instructions and their optimization are done using the system. Maintenance management system also provides daily operational activities and reporting on them (PM plans, breakdown repairs, refurbishment work, etc.). The system also provides information on maintenance work already done and planned. The system is also used to make necessary material and resource purchases and manage spare parts operations. In addition, the system contains the equipment hierarchy and supplier information. In below Figure 10 shows the main menu of Novi.

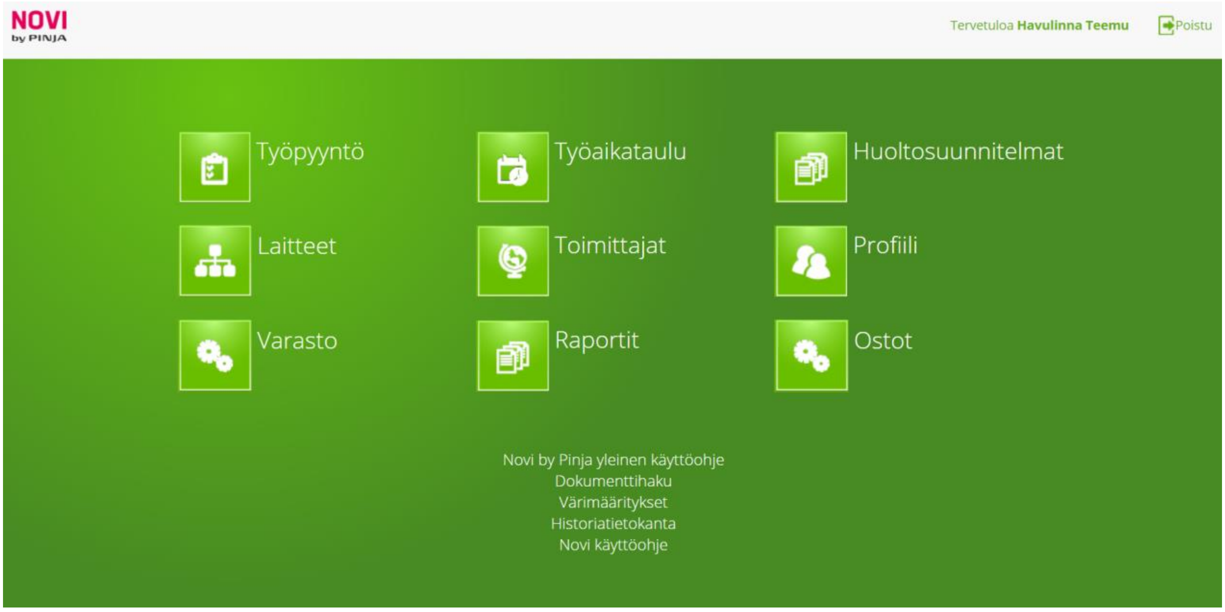

Figure 10. The main menu of maintenance management system, Pinja Novi.

Preventive maintenance plans are on a separate tab in the system, and editing and adding them takes place there. Preventive maintenance plans consist of calendar and route maintenance. Mechanical maintenance mainly uses route maintenance. Route maintenance consists of different route maintenance levels, which consist of different work packages, i.e. route maintenance, depending on the intervals of route maintenance. Work packages, i.e. route maintenance, consist of equipment-specific route maintenance points, i.e. actual preventive maintenance instructions. Figure 11 below shows the user's view of the different route maintenance levels and their information.

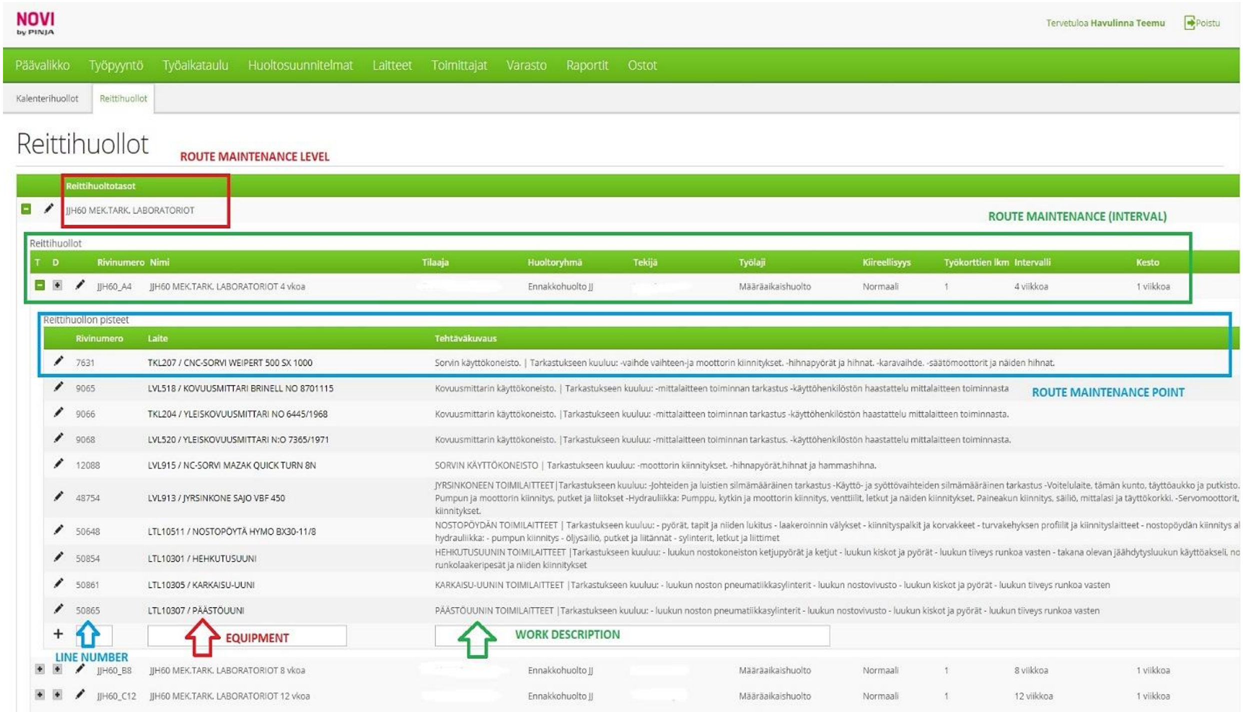

Figure 11. The different levels of preventive maintenance plans and the information they provide to users.

2.3.3 Promas – production data logging software

Promas is an SQL-based software that collects data from production. The system registers various production and maintenance information, such as different analysis, melting and failure information. This thesis utilizes failure information provided by Promas system from various equipment. The system can delimit various desired information such as failure type, department and fault time. Promas saves a variety of information about failures, such as start and end time, duration, area, equipment, failure type, cause, effect and description. This data can be transferred to Excel for processing and more detailed analysis. In Figure 12 below is the data provided by Promas.

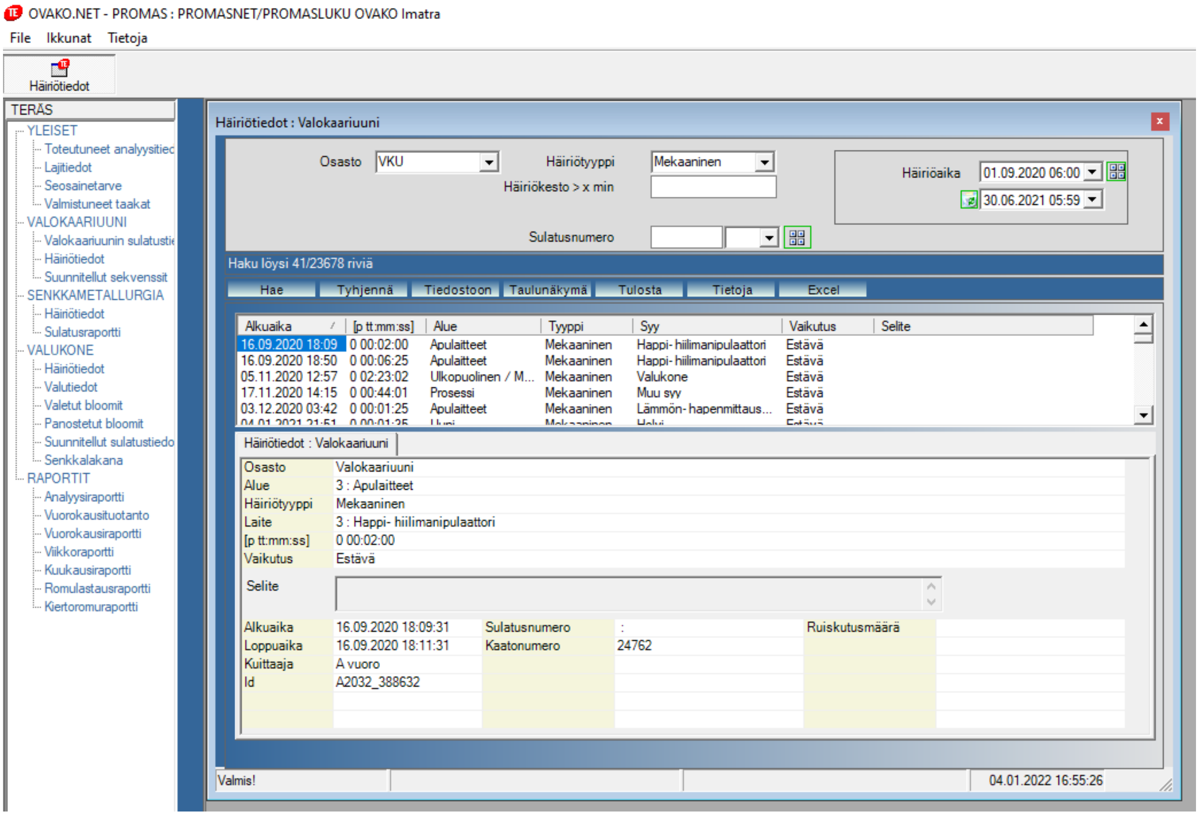

Figure 12. Information provided by Promas system to users.

2.4 Summary of theory and methods section to achieve results

In order to achieve the results of the thesis, the most important methods and theories that lead to results are compiled from the section. Methods of the thesis forms a triangulation (literature review, databases of Ovako and risk analysis methods) with which results are achieved. Figure 13 below shows the connection between triangulation, theory, methods and results and how results are achieved.

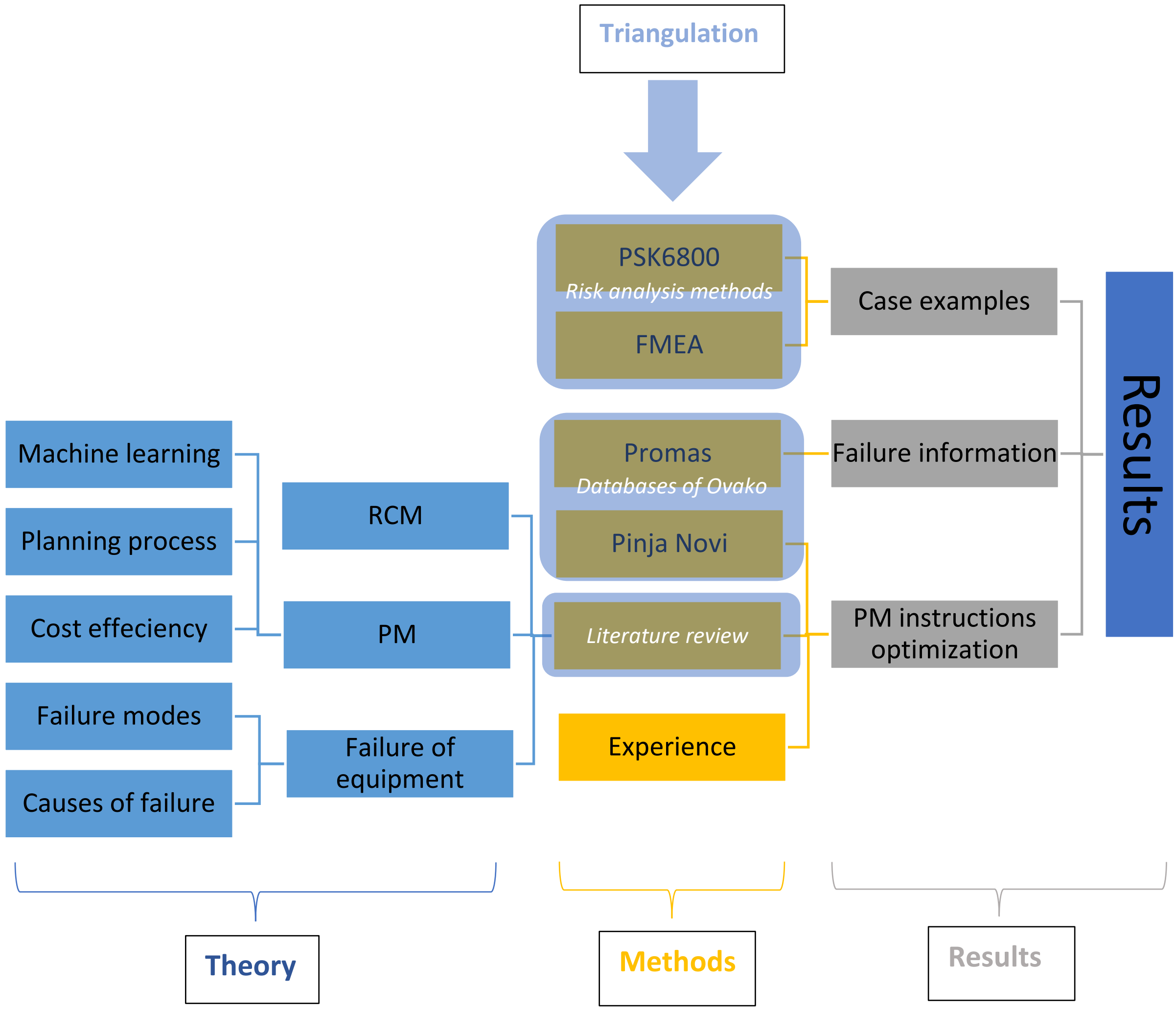

Figure 13. Connection between triangulation, theory and methods to achieve results of the thesis.

Maintenance focused literature review forms the theory of the thesis. In addition to my experience, the literature review is used to optimize preventive maintenance instructions in the results section. Actual modification of preventive maintenance instructions is performed in maintenance management system Pinja Novi. Pinja Novi and Promas systems form the databases of Ovako, which is one of the methods of thesis. Promas system is used to determine the most faulty equipment and areas of the selected mill. The third method of thesis is risk analysis methods, i.e. criticality classification (PSK6800) and FMEA that forms the results of the case examples.

3. Results and analysis

Results and analysis section presents the results obtained from the different areas and analyses the information provided by them. Results to be considered are determination of the current situation of preventive maintenance at the mill, finding the most faulty equipment and areas based on failure information, case examples (utilizing risk analysis methods), optimization of the current preventive maintenance instructions and demonstration of future procedure instructions. Results obtained are presented in the sections below.

3.1 Current preventive maintenance situation at the mill

Performing preventive maintenance actions at a steel mill differs in many respects from performing preventive maintenance at a paper or board mill, for example. High acting forces on equipment and high temperatures significantly put the strain on equipment, increasing the need for preventive maintenance. Preventive maintenance at Ovako's steel mill is mainly performed by its own preventive maintenance employees. There are a total of five mechanical preventive maintenance employees and a reliability engineer supervising them. Preventive maintenance employees perform weekly route maintenance in their respective areas of responsibility and report these to the maintenance management system and their supervisor. However, for example, equipment condition monitoring measurements and lubrication maintenance are outsourced to subcontractors.

Ovako's mechanical preventive maintenance activities can be roughly divided into mechanical inspections and lubrication maintenance. Mill own preventive maintenance employees perform mechanical inspections and outsourced lubrication maintenance employees perform lubrication route maintenance. In addition, condition monitoring measurements of the equipment are performed five times a year. However, the mill has still made little use of the benefits of real-time condition monitoring and machine learning in its maintenance operations.

3.2 The most faulty areas and equipment

The section presents the most faulty equipment in the steel mill and heavy bar mill. The failure information of equipment has been obtained through Promas system and filtered in Excel into the correct format. Time period for reviewing failure information is September 1, 2020 to June 30, 2021. No major production shutdowns were scheduled for that time period. The failure information in the sections below is more detailed for each equipment.

3.2.1 The failure information: Steel mill

Table 2 below shows the failure information that led to equipment failure of the steel mill. Failures are divided into three groups; areas, equipment and equipment hierarchy. The failure information under consideration is filtered to take into account only mechanical and production stopping faults. Faults are reported in both hours and number of amount. There are total 244,2 hours and 58 amount production stopping mechanical failures. The highest amount of failure is in the electric arc furnace area (hourly).

Table 2. Mechanical failures in hours and number of amount in Steel mill based on area and equipment.

Row Labels	Column Labels Mechanical Sum / Hours	Sum / Amount
"Lack of melt material"	**218,9**	**51**
Electric arc furnace	**156,4**	**35**
Roof lift and turning equipment	72,9	12
Power cables	18,8	1
Water cooling system	17,7	5
Lime injector	15,5	6
Carbon injector	13,9	3
Dust collection system	8,3	2
Other equipment	5,2	3
Lance manipulator	2,8	1
Electrode arms	1,0	1
Hydraulic	0,4	1
Ladle furnace	**62,5**	**16**
Mechanical vacuum pumps	19,8	9
LF roof components	15,0	3
Alloying system	11,7	2
Melt transfer equipment	11,1	1
Ladles	4,9	1
Segments	**14,1**	**2**
Segments	**14,1**	**2**
Cooling system	10,0	1
Segment change	4,1	1
Oscillation	**7,3**	**2**
Moulds	**7,3**	**2**
Hydraulic	6,8	1
Water cooling systems	0,5	1
Torch cutting	**3,4**	**2**
Torch cutting machine	**3,4**	**2**
Cutting machine	2,9	1
Measuring roll	0,5	1
Rotating machine	**0,5**	**1**
Ladle turret	**0,5**	**1**
Hydraulic	0,5	1
Grand total	**244,2**	**58**

Figure 14 is an illustrative graph showing the distribution of failures to different areas, equipment and equipment hierarchies. In the graph, hours are indicated in blue colour and quantities in red colour.

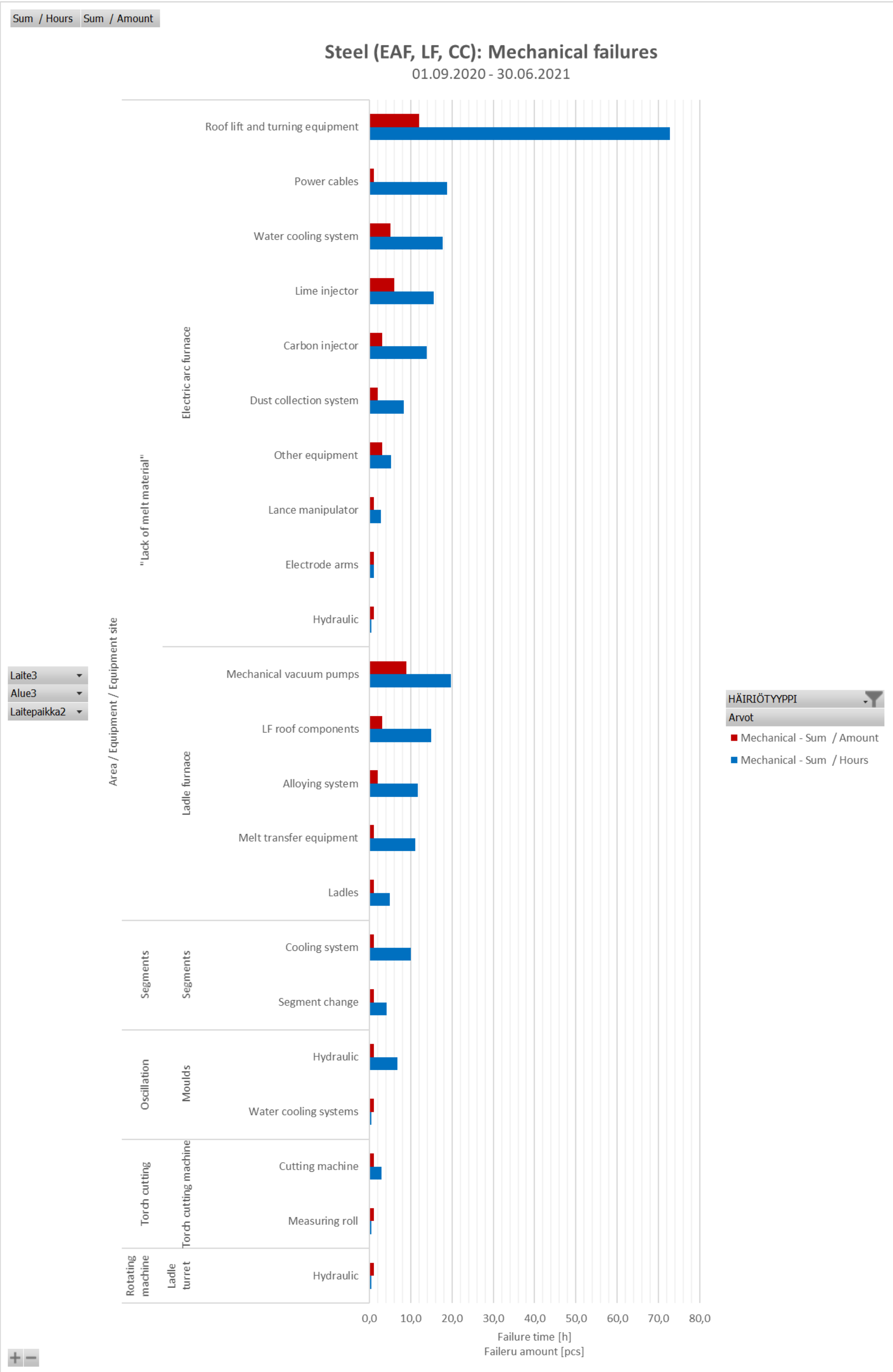

Figure 14. Mechanical failures in Steel mill based on area and equipment.

It is noticeable from the failure information that there have been many failures during the time period, especially in the area of roof lift and turning equipment. These failures are mainly due to faults in the main bearing. However, there have also been many failures at the ladle furnace (LF) area and other equipment in the electric arc furnace (EAF), for example. However, there was no apparent reason why the failure had occurred for all failures. In addition, the classification of failures in Promas system for different areas and equipment was deficient, which made it challenging to analyse failures. In the steel mill, the electric arc furnace equipment is selected for case examples and optimization of preventive maintenance instructions.

3.2.2 The failure information: Heavy bar mill

Table 3 below shows the failure information that led to the equipment failure of the heavy bar mill. Failures are divided into two groups; area and equipment. The failure information under consideration is filtered to take into account only mechanical and production stopping faults. Faults are reported in both hours and number of amount. There are total 113,0 hours and 171 amount production stopping mechanical failures. The highest amount of failure is in the 1st rolling stand area (hourly).

Table 3. Mechanical failures in hours and number of amount in Heavy bar mill based on area and equipment.

Row Labels	Column Labels Mechanical Sum / Hours	Sum / Amount
1st rolling stand	**25,0**	**42**
Manipulators (all equipment)	9,5	16
Transfer equipment	6,4	2
Roller conveyor (descaler to roller conveyor (front))	2,0	3
Lubrication system	1,9	6
Rolling stand + couplings	1,7	6
Chester (gearbox)	1,1	2
Roller conveyor (front)	0,9	1
Roller conveyor (behind)	0,6	2
Rollingmotor + Tyrak	0,4	1
Water cooling system	0,3	2
Bridge crane 25 / 6,3 t	0,2	1
Profile rolling stands	**20,6**	**30**
Turning equipment	14,2	13
3rd rolling stand	4,0	14
Rollingmotor V4	1,0	1
2nd rolling stand	0,8	1
Transfers	0,6	1
Hot saw 2	**20,3**	**33**
Scrap pushers	5,0	9
Other equipment	4,4	7
Roller conveyors	4,2	7
Pressers	2,3	2
Transfer chains	1,6	2
Profile grave	1,0	1
Cooling bed 1 (driving gear)	0,9	1
Stamping device 2	0,6	2
Measuring roll	0,2	1
Cooling bed (grave) (driving gear)	0,1	1
Bloom furnace	**18,9**	**5**
Furnace heating	14,6	1
Furnace driving system	2,0	1
Descaler	1,7	2
Hot bumper	0,6	1
Strapping	**16,7**	**46**
Strapping machines	12,9	34
Presser rollers	1,7	3
Circular strapping	1,1	6
Transfer equipments	0,4	1
Load table	0,4	1
Cooling bed 2 (driving gear)	0,2	1
Billet cutter	**5,8**	**6**
Measure limiter	5,0	1
Cutter (Motor + Coupling + Blades)	0,4	2
Stamping device	0,3	2
Rolls (front)	0,1	1
Hot saw 1	**4,2**	**5**
Measure equipment (all limiters)	3,1	3
Other equipment (hot saw 1)	0,6	1
Roller conveyor	0,5	1
Chamfering equipment	**1,6**	**4**
Other	1,6	4
Grand total	**113,0**	**171**

Figure 15 is an illustrative graph showing the distribution of failures to different areas and equipment. In the graph, hours are indicated in blue colour and quantities in red colour.

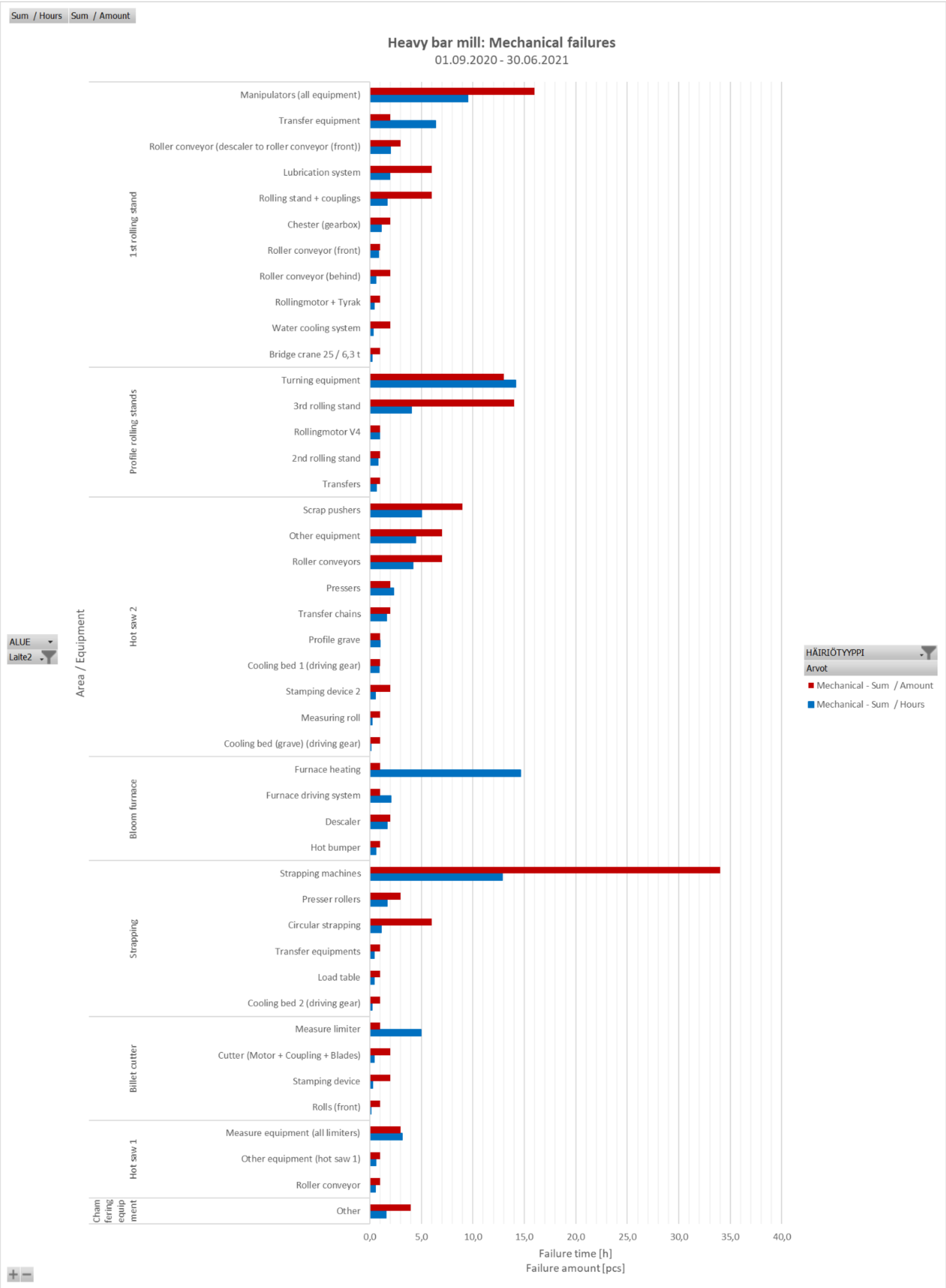

Figure 15. Mechanical failures in Heavy bar mill based on area and equipment.

It is noticeable from the failure information that there have been many failures during the time period, especially in the areas of manipulators and strapping machines. However, there have also been many failures at the profile rolling line, for example. However, there was no apparent reason why the failure had occurred for all failures. In addition, a few failures were registered in the heavy bar mill failure information that were not due to equipment failure. From the heavy bar mill, equipment of the 1st rolling stand and strapping machines are selected for case examples and optimization of preventive maintenance instructions.

3.3 Case examples

Case examples of the thesis highlight new development options for preventive maintenance. The risk analysis methods used in case examples are criticality classification of equipment in industry based on PSK 6800 standard and FMEA, failure mode and effects analysis. Areas of case examples have been selected based on the most faulty areas mentioned above. The electric arc furnace (EAF) area is selected on steel mill and the area of the 1st rolling stand and strapping machines on heavy bar mill. More detailed analyses and their steps are given in the sections below.

3.3.1 Criticality classification of equipment in industry (PSK 6800)

Based on the failure information obtained, the areas to be considered in the critical classification of case examples are selected. Equipment in these areas are listed in the criticality classification table that identifies the most critical equipment in the areas. Appendices 1 and 2 provide detailed criticality classification tables for each area separately. Based on the results obtained, the criticalities of the equipment are classified into four different categories; noncritical, normal, critical and very critical equipment. Table 4 below shows the limit values and distribution of these four categories and Figure 16 illustrates the results obtained. Results combine steel mill and heavy bar mill equipment and their criticalities.

Table 4. Limit values and distribution of criticality classification.

Criticality	Criticality index K	Amount	%
1 – noncritical	<1000	10	44 %
2 – normal	>1000 - <2500	7	30 %
3 – critical	>2500 - <4000	5	22 %
4 – very critical	>4000	1	4 %

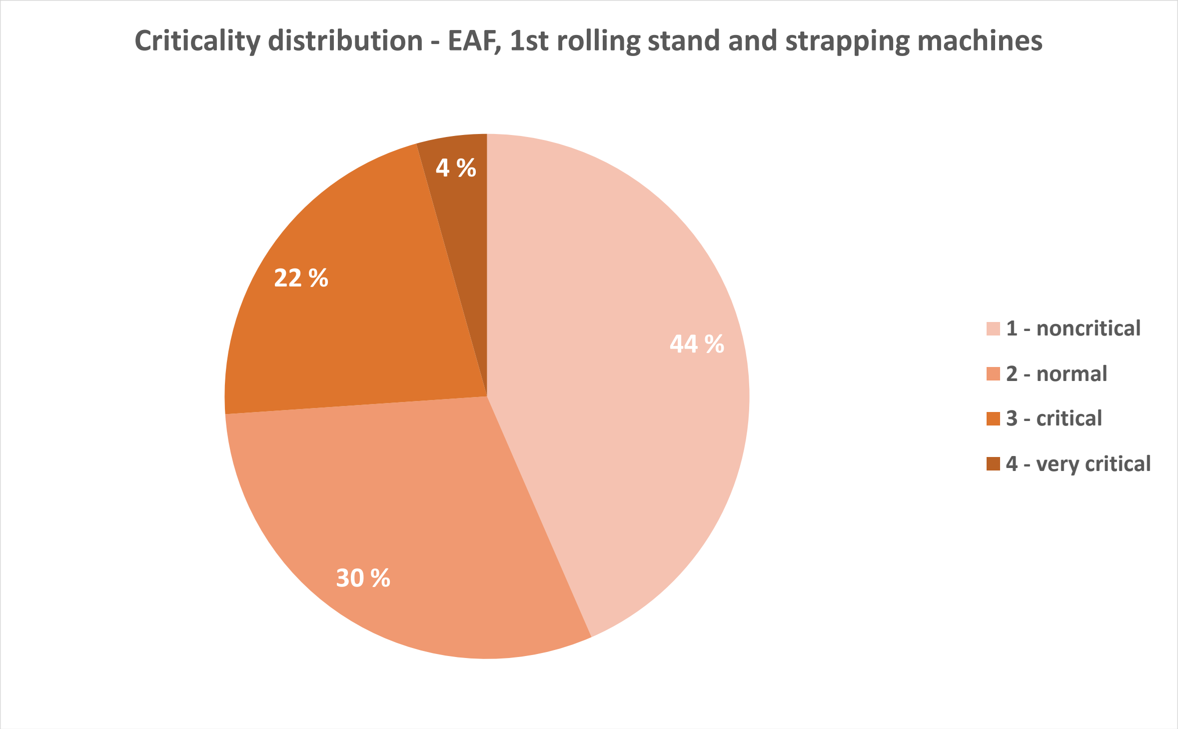

Figure 16. The distribution of equipment criticality of EAF, 1^{st} rolling stand and strapping machines areas.

As can be seen from the table and figure, the criticalities are evenly distributed. However, the quantity of noncritical and normal critical equipment is the highest. But the quantity of critical and very critical equipment, for example, is too high. However, the limit values for criticality indexes are high level and it would be desirable to reduce the criticality of critical equipment in the future in particular.

In criticality classification of equipment in industry, the coefficients for the different components are estimated for each equipment based on PSK 6800 standard. Taking these coefficients and weight factors into account, a total criticality index is formed. In addition, the calculation takes into account weight factors of production loss. For steel mill, this value is 36 and heavy bar mill value is 24. Table 5 below shows criticality classification for the most critical equipment in both steel mill and heavy bar mill. Table also shows the coefficients of each equipment and their ranges, as well as the total criticality indexes.

Table 5. Criticality classification for the most critical equipment.

Identifier of object	SU0715	KV0965
Name of object	Roof lift and turning equipment	Manipulator (all components)
Time between failures (1…8)	8	8
Safety risks (0…16)	8	8
Environmental risks (0…16)	4	2
Production loss (0…4)	4	2
Quality costs (0…4)	2	2
Repair costs (0…4)	4	4
Criticality index K	**4832**	**3744**

From criticality classification, it can be seen that repair costs, production losses and time between failures, in particular, are significant critical factors. Especially in the case of roof lift and turning equipment, repair costs and production losses significantly raise the criticality index. Also, for example, time between failures of manipulators is often short, which raises the overall criticality index considerably. Environmental risk and quality costs do not play a significant role in raising the criticality index in either case.

3.3.2 Failure mode and effects analysis (FMEA)

Failure mode and effects analysis examines selected equipment based on the criticality classification, i.e. roof lift and turning equipment and manipulators equipment. Failure mode and effects analysis has been performed based on equipment hierarchy for the different components of these two equipment. Appendices 3 and 4 provide more detailed results of the analysis. The excel template used for FMEA has been modified from the pFMEA template used by Ovako, better suited to maintenance needs. Excel template consists of three sections, which are divided into the current situation, suggestions for improvement and the effects of improvement. However, the thesis focuses on assessing current situation. On the other hand, suggestions for improvement brought about by FMEA, for example, will be useful in optimizing current preventive maintenance instructions.

Table 6 shows the most critical components of both roof lift and turning equipment and manipulators equipment. The criticality of components is determined using the RPN coefficient, in which case the component with the highest risk priority number is the most critical. Based on the analysis, the table also lists failure modes, effects of failures, causes of failures, controls to detect failures and recommended suggestions for improvement.

Table 6. Failure mode and effects analysis for the most risk components.

Equipment ID	SU0715	KV0965
Equipment	Roof lift and turning equipment	Manipulator (all components)
Component	Main bearing	Support frame and wheel
Failure mode	Adhesive wear	Brittle fracture
Effects of failure	Locally: Slows roof turning operation	Locally: Operation of the controller pair is interrupted
	Other process: Effects entire melting process	Other process: Rolling process fails
Severity (1-10)	10	6
Cause of failure	Lack of lubrication High forces and torsions	High forces
Occurance (1-10)	2	6
Controls to detect failure	Preventive maintenance inspections	Preventive maintenance inspections
Detection (1-10)	7	7
RPN	**140**	**252**
Recommended actions	- Cleanings - Online condition monitoring system - Optimized lubrication (new lubrication system)	- Cleanings - Inspection and replacement of wearing components or constructions

Based on the failure mode and effects analysis, many possible failure modes appear in the components of roof lift and turning equipment and manipulators. However, wear, fracture, fatigue and leakage in the various components are apparent. And often, those failures have a significant impact on production and its productivity. FMEA also reveals the causes of potential failures, which are often impurities, ageing, acting forces and lack of lubrication. The analysis also shows that effective preventive maintenance, routine maintenance and annual maintenance can detect incipient failures in a timely manner prior to final failure.

Recommended suggestions for improvement include regular cleaning, inspection and replacement of wearing components, modernization and regular maintenance of lubrication systems, and utilization of online condition monitoring at the most critical equipment. These improvements could lower the risk priority of equipment and components, ensuring equipment availability.

3.3.3 Supplemented SWOT analysis for risk analysis methods

Thesis uses supplemented SWOT analysis, i.e. 8-field analysis. The analysis is used to evaluate risk analysis methods both nowadays and in the future. Analysis consists of strengths, weaknesses, opportunities and threats that assess the current situation. While success factors, weaknesses to strengths, threats to strengths and possible crisis situations assess different future scenarios, developing operations. When considering features, the aim is to highlight the benefits and disadvantages of each method and the reasons why they should or should not be used in the development of preventive maintenance. Table 7 below shows supplemented SWOT analysis related to criticality classification of equipment.

Table 7. Supplemented SWOT analysis for criticality classification of equipment (PSK6800)

Criticality classification of equipment (PSK6800)	**1. Strengths** • Easy and fast method to determine the most critical equipment • A clear standard to follow • Consideration of production loss in classification	**2. Weaknesses** • A superficial classification that may give a false impression of the criticality of equipment • The scaling and editing of sub-coefficients and weight factors should be considered
3.Opportunities • Helps an inexperienced maintenance employee assess equipment criticalities • Can quickly and easily list the entire equipment of the mill in critical order • Enables the success of external and internal audits	**5.Success factors (1+3)** • Simplicity and clarity • A quick way to list the most critical equipment in mill, taking into account production loss • Complies with standard, an advantage in audits	**6.Weaknesses to strengths (2+3)** • A superficial criticality classification may reveal important equipment • Inexperienced maintenance employee gets to know the mill equipment quickly and easily
4.Threats • Incorrect evaluation of equipment criticality • The analysis does not correspond to the workload used for it	**7.Threats to strengths (1+4)** • The analysis is easy and quick to perform again	**8.Possible crisis situations (2+4)** • Criticality classification is performed incorrectly and the error is not detected • Does not correspond to the workload and is superficial

Strengths and opportunities for criticality classification are its ease and the clear standard to follow. As well as taking production loss into account with a quick criticality classification, it has the advantage. Strengths and opportunities form success factors for criticality classification, including its ease and clarity and the standardized way to list equipment in criticality order. Weakness in criticality classification is its superficiality, which may give a false impression of equipment criticality. However, a superficial analysis may bring a new perspective to criticality classification. The misuse is perceived as a threat that does not support the development of preventive maintenance in a more reliable direction. However, the analysis is easy and quick to perform again. On the other hand, a possible crisis situation is misusing criticality classification and errors are not noticed.

Table 8 shows supplemented SWOT analysis for another risk analysis method, i.e. failure mode and effects analysis. The table lists, respectively, strengths, weaknesses, opportunities, threats, success factors, weaknesses to strengths, threats to strengths and possible crisis situations.

Table 8. Supplemented SWOT analysis for failure mode and effects analysis (FMEA)

Failure mode and effects analysis (FMEA)	**1.Strengths**	**2.Weaknesses**
	• Identification of faults and failure modes, which if they occur adversely affect performance • Assessment of cause and effect of the failure • Create a logical model for estimating faults and abnormalities • Assists in the development of preventive maintenance strategy and schedule	• Laborious and challenging to perform for complex equipment • For the identification of individual failure modes, not for combinations • The effect of human error or maintenance is not included in the analysis
3.Opportunities	**5.Success factors (1+3)**	**6.Weaknesses to strengths (2+3)**
• Direct operations towards reliability centered maintenance. • Ensures that equipment failure modes and their effects are considered • Enables the success of external and internal audits • Helps in selecting reliable planning options	• Effective determination of equipment failure modes and effects • A logical model to direct operations toward RCM • Assists in the development of preventive maintenance strategy, planning and scheduling	• The analysis is laborious but guarantees a detailed examination
4.Threats	**7.Threats to strengths (1+4)**	**8.Possible crisis situations (2+4)**
• Incorrect assessment of failures and their causes • Forgetting critical operations in the analysis • The analysis does not correspond to the workload used for it	• Incorrect evaluation may reveal new failure modes and effects	• No correct failure mode or effect is detected • The analysis directs preventive maintenance to wrong action

The strength of failure mode and effects analysis is, among other things, its depth in identifying cause, consequence and failure mode. While the opportunity of FMEA is considered to be, among other things, its guidance towards reliability centered maintenance (RCM), and use of FMEA in audits is considered a good thing. These form success factors that ensure a logical analysis method that helps develop preventive maintenance strategy, planning and scheduling. However, FMEA is often considered a laborious and complex method. On the other hand, the analysis provides a detailed examination. The misuse is perceived as a threat and a possible crisis situation, which does not recognize correct failure modes and effects, and does not support the development of preventive maintenance in a more reliable direction.

3.4 Optimizing preventive maintenance instructions

The most important part of the thesis, i.e. the optimization of existing preventive maintenance instructions, deals with current preventive maintenance instructions, their optimization and presents procedure instructions for the development of maintenance instructions in the future. The thesis is limited to preventive maintenance instructions of the most faulty equipment in steel mill and heavy bar mill, so that content of the thesis does not become too outsized. Preventive maintenance instructions under consideration are instructions for the most faulty areas of steel mill and heavy bar mill, i.e. electric arc furnace and the 1st rolling stand -areas.

3.4.1 Current preventive maintenance instructions

As previously described in theory and methods section, mechanical route maintenance consists of many different levels in the new maintenance management system. These levels are route maintenance levels, route maintenance intervals and route maintenance points. The actual optimization of preventive maintenance instructions is done by modifying route maintenance points and the information they provide. Figure 17 below shows content and scope of the current preventive maintenance instructions under consideration. One of the problems with current preventive maintenance instructions has been their narrowness and partly outdated information about, for example, the equipment base or need for preventive maintenance required by equipment. Also, the intervals of current preventive maintenance are partly too long and unnecessary route maintenance points occur in many route maintenance. Thus, failure of some equipment may have been due to inadequate preventive maintenance, to which a solution is sought in the following section.

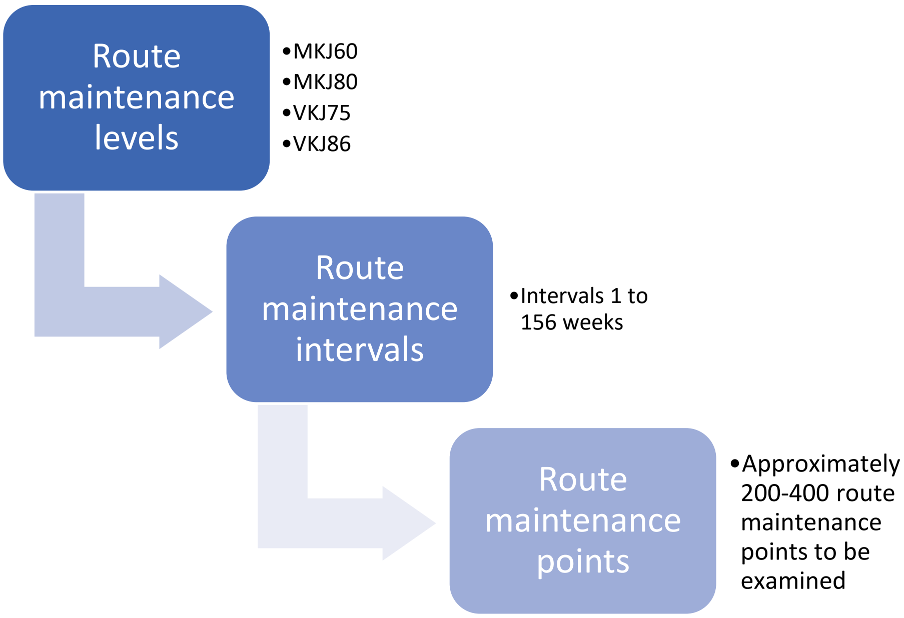

Figure 17. Route maintenance levels, route maintenance intervals and route maintenance points are considered in the thesis.

The above-mentioned route maintenance levels are considered in the thesis, of which MKJ-abbreviation is route maintenance level of equipment of steel mill and VKJ is route maintenance levels of equipment of heavy bar mill. Intervals between these work packages, i.e. route maintenance, intervals differ between 1 and 156 weeks. So overall, the thesis examined about 200-400 route maintenance points. There are an estimated 9000 mechanical and electrical route maintenance points throughout the mill.

3.4.2 Optimized preventive maintenance instructions

The optimization of the preventive maintenance instructions begins with examining the above failure information. Examination looks at causes of failures that led to the malfunction and considers whether the malfunction could have been avoided with more effective preventive maintenance operations. Optimization of the preventive maintenance instructions also utilizes suggestions for improving failure mode and effects analysis of the case examples and perspective what they bring. Based on failure information and failure mode and effects analysis, route maintenance and route maintenance points that require optimization are appraised and listed. In this context, new route maintenance points will also be created as needed. Optimizations and creation of new route maintenance points are initially performed in an excel file, from which the data is transferred to the route maintenance tabular of maintenance management system Novi.

Table 9 shows optimizations related to the preventive maintenance instructions for equipment of EAF area in steel mill and additions of new preventive maintenance instructions. The table lists equipment, types of preventive maintenance, current intervals and optimizations to be performed.

Table 9. Optimizations or modifications to preventive maintenance instructions – Steel mill.

Equipment	Mechanical inspection MKJ60	Lubrication maintenance MKJ80	Current interval (week)	Optimizations or modifications to PM instructions
Roof lift and turning equipment	X		4	-Inspecting operation of the lubrication system -Reporting of uncleaning -Changing intervals
	X		8	
Power cables	X		-	-New maintenance instructions (inspecting the power cables for wear)
Water cooling system	X		-	-New maintenance instructions (inspecting hoses and pipes)
Bottom stirring system	X		-	-New maintenance instructions (inspecting equipment)
Carbon injector (Stein)	X		-	-New maintenance instructions (inspecting valves and detecting blockages)
Lime injector (Stein)	X		-	-New maintenance instructions (inspecting valves and detecting blockages)

Optimization of preventive maintenance instructions and modifications to be made are based on information provided by failures and case examples. In particular, the failure in the main bearing of roof lift and turning equipment increases the need to renew the lubrication system or inspect its function. There will also be a need in the future to implement condition monitoring on the main bearing of roof lift and turning equipment so that a corresponding failure is detected on time. As can be seen from the table, new maintenance instructions have also been created, based on inadequate preventive maintenance actions. In particular, equipment and components for other components in arc furnace area, such as power cables, water cooling system, carbon and lime injectors, and bottom stirring system, require preventive maintenance. The actions on these new maintenance instructions are primarily based on mechanical inspections, including component wear reporting and inspections of valves, hoses and piping, for example. Steel mill production produces a huge amount of impurities (dust), which damages equipment prematurely. Therefore, impurity reporting should be added to many preventive maintenance instructions to ensure optimal preventive maintenance for equipment. In steel mill, maintenance instructions are also partly in wrong hierarchies, which can cause confusion or not be carried out. In steel mill, intervals of preventive maintenance instructions should also be optimized according to the life cycle and conditions of equipment. The equipment base is partly obsolete, which increases the need for preventive maintenance. Table 10 below shows intervals optimizations of preventive maintenance instructions based on the mathematical calculation equation of the theory part. The table shows equipment, current intervals, unavailability value, MTBF value and optimized interval for the new preventive maintenance instruction. More detailed calculations are given in Appendix 5.

Table 10. Optimization of preventive maintenance intervals for EAF equipment

Equipment	Current interval (week)	Unavailability	MTBF (week)	Optimized interval (week)
Roof lift and turning equipment	4	0,04	26	2
	8		52	4
Power cables	-	0,04	52	4
Water cooling system	-	0,04	52	4
Bottom stirring system	-	0,04	52	4
Carbon injector (Stein)	-	0,04	52	4
Lime injector (Stein)	-	0,04	52	4

The table lists interval optimizations for all new and optimized maintenance instructions. Intervals for the different route maintenance points are listed at the table, below each other, as are MTBF values. In all cases, 4 percent is used as an unavailability value, which is set below the disturbance percent requirement of the maintenance organization, i.e. 5 percent. MTBF values are determined on equipment-by-equipment based on failure information. And optimized intervals required for equipment are calculated in the right-hand column. From optimized intervals, it is noticed that mean time between failures of equipment is short in the steel industry, which also increases the need for preventive maintenance required for equipment, i.e. maintenance intervals should be shortened in many different cases.

Table 11 shows optimizations related to preventive maintenance instructions for the equipment of 1st rolling stand area in heavy bar mill and additions of new preventive maintenance instructions. The table lists equipment, types of preventive maintenance, intervals and optimizations to be performed.

Table 11. Optimizations or modifications to preventive maintenance instructions – Heavy bar mill.

Equipment	Mechanical inspection VKJ75	Lubrication maintenance VKJ86	Current interval (week)	Optimizations or modifications to PM instructions
Manipulators (all equipment)	X		4	-Reporting of uncleaning -Alignment of the motor and gearbox -Inspection of hydraulic cylinders, hoses, pipes and fittings -Changing intervals
		X	12	
		X	24	
		X	156	
Transfer equipment	X		4	-Reporting of uncleaning -Changing intervals
	X		12	
Lubrication system	X		-	-New maintenance instruction (inspection of hydraulic rooms (cylinders, hoses, pipes, fittings))
Roller conveyor (behind)	X		-	-Inspection of lubrication dispensers -Checking the lubrication of bearings of rollers -Reporting of lubrication leaks
Roller conveyor (front)	X		-	-Inspection of lubrication dispensers -Checking the lubrication of bearings of rollers -Reporting of lubrication leaks
Roller conveyor (descaler to roller conveyor (front))	X		-	-Reporting of lubrication leaks

As can be seen at the table, the production of heavy bar mill also produces impurities that are detrimental to the reliability of equipment, which must be reported. There are many problems in the lubrication system on roller conveyors and grease leaks cause problems for equipment and production. With the help of preventive maintenance, these leaks can be detected in time and able to react to them. Many problems with hydraulic cylinders, hoses and pipes are also observed in the area of manipulators, so these inspections should be increased. There have been many failures in gearboxes and electric motors of the manipulators during the last year, so gearboxes should be added to condition monitoring and gearboxes and motors alignment should be inspected at regular intervals. Equipment base in the 1st rolling stand area is also obsolete, which means that preventive maintenance required by equipment is increasing, i.e. optimization of intervals must meet the need. Table 12 below shows intervals optimizations of preventive maintenance instructions based on the mathematical calculation equation of the theory part. The table shows equipment, current intervals, unavailability value, MTBF value and optimized interval for new preventive maintenance instruction. More detailed calculations are given in Appendix 5.

Table 12. Optimization of preventive maintenance intervals for 1st rolling stand equipment

Equipment	**Current interval (week)**	**Unavailability**	**MTBF (week)**	**Optimized interval (week)**
Manipulators (all equipment)	4	0,04	26	2
	12		104	8
	24		156	12
	156		-	104
Transfer equipment	4	0,04	26	2
	12		52	4
Lubrication system	-	0,04	52	4

The table lists interval optimizations for all new and optimized maintenance instructions. Intervals for the different route maintenance points are listed at the table, below each other, as are MTBF values. In all cases, 4 percent is used as an unavailability value, which is set below the disturbance percent requirement of the maintenance organization, i.e. 5 percent.

MTBF values are determined on equipment-by-equipment based on failure information. And optimized intervals required for equipment are calculated in the right-hand column. From optimized intervals, it is noticed that mean time between failures of equipment is short in the steel industry, which also increases the need for preventive maintenance required for equipment, i.e. maintenance intervals should be shortened in many different cases. Also, oil change interval for the gearbox of manipulator should be shortened from the current 156 weeks to 104 weeks, increasing the reliability of the gearbox.

3.4.3 Procedure instruction for the future

As a summary of the thesis and at the same time "Optimization of preventive maintenance instructions" section, the procedure instructions for the development of preventive maintenance are used to create in the direction of reliability centered maintenance. The instruction also aims to provide a clear framework for how route maintenance plans will be modified or created in new maintenance management system in the future, and their structure in general. Instruction is utilized in internal guidelines and training material of Ovako. A more detailed procedure instruction is attached in Appendix 6 and its contents are summarized in three pages (A4).

Initially, instruction provides general information about the contents and its coverage. The methods for determining the most critical equipment and their failures are also presented at the beginning. These methods have also been utilized in this thesis and support the logical process of developing preventive maintenance. The following section provides an overview of the structure and classification of route maintenance plans. Instruction also provides guidelines on filling or modifying route maintenance plans and what information they should contain. Finally, instructions for filling the work description of route maintenance point are given and an example of a well-completed work description is also given.

4. Discussion

The aim of the research was to develop and modernize preventive maintenance and its operation as part of the maintenance management system renewal project. Theory and results of the research provided potential development methods for preventive maintenance of the mill. The main focus of the research is on the optimization of current preventive maintenance instructions as well as development methods that support the optimization process. Results of the thesis also provide a more detailed analysis of equipment failures based on failure information. In addition, an important element in the development of preventive maintenance is the use of new standardized methods for evaluating equipment failures and criticality. This section discusses results and development methods in more detail and the benefits what they bring to maintenance.

4.1 Key findings

Content of the thesis is very extensive and gives many different results to the case company and the reader. The main findings of the thesis can be found in theory, methods and results sections. The importance of preventive maintenance for reliable maintenance is picked up from theory section. The section presents the steps in preventive maintenance planning, benefits of machine learning in the planning process and attributes of cost-effective preventive maintenance planning. Theory section also presents different failure modes based on time and causes behind the failures. These are especially helpful for failure mode and effects analysis. The section also presents the risk analysis methods used in results, one of the most important findings and methods in the thesis.

Results of the thesis are divided into three main themes; identifying the most faulty areas and equipment, case examples of risk analysis methods and optimization of preventive maintenance instructions. The most faulty areas and equipment were determined based on failure information. In steel mill area, there were 58 failures and about 244,2 hours. The most faulty area was EAF and the most faulty equipment was roof lift and turning equipment. At heavy bar mill, there were 171 failures and 113,0 hours. The most faulty area was 1st rolling stand and the most faulty equipment was manipulators equipment. The results show that failures in steel mill are longer lasting but occur less frequently than in heavy bar mill. Faults in different areas and equipment during the time period are easily noticed from the failure information.

The case examples illustrate how risk analysis methods can be put into practice. From criticality classification of equipment, it is noted that criticalities are distributed with selected equipment according to RCM specifications. Of course, the limit values for criticality index are quite high. Also, based on criticality classification, roof lift and turning and manipulator equipment was selected as the most critical equipment. The aim of FMEA was to identify the most critical components for selected equipment and examine their failure modes, effects, causes and recommended improvement actions. The analyses revealed reasons for the failures including, among other things, lack of lubrication, high applied forces and ageing of equipment. Recommended improvement actions include reporting impurities, regular replacement of wearing parts, replacement of lubrication systems and increased condition monitoring at critical equipment.

Optimizing preventive maintenance instructions and plans was the most challenging part of the thesis. The review of instructions was limited to four route maintenance levels; MKJ60, MKJ80, VKJ 75 and VKJ 86. The route maintenance levels were further divided into different maintenance intervals, of which about 200-400 route maintenance points were examined. The optimization of route maintenance points was started by considering whether the failure could have been prevented by preventive maintenance actions, and based on a positive response, changes were considered. As the results show, there was a need for optimization in many instructions. For example, there were shortcomings in intervals and contents of the instructions. There were also duplicate and old maintenance instructions in the maintenance management system. These shortcomings and needs have been optimized by planning new and updating old maintenance instructions. The changes are documented in the maintenance management system. The instructions for creating new maintenance instructions and updating old ones in the section will also create a unified model for optimizing maintenance instructions in the future.

4.2 Reliability and validity of results

Reliability of the results is used to check whether the obtained results have been determined in the right way. While validity analysis looks at whether the right things have been determined or measured. In the equipment failure information, the results proved to be largely reliable. Factors that increase the reliability of failure information include the fact that the data was taken directly from Promas system and the data has not been modified before running in Excel. However, the validity of failure information is compromised by incomplete and vague classification and reporting of failures. The causes, consequences, equipment or component of failures were often not accurately reported. Failures may also have been targeted to the wrong area or equipment. For these reasons, failure information had to be analysed and rearranged in Excel.

Results of the case examples are primarily reliable and valid. The reliability of results is confirmed by using scientific sources in the risk analysis methods, and there is also a clear standard behind it. However, differences in interpretation may occur when calculating the criticality index and the risk priority number. The difficulty of defining these values reduces the reliability of the results. Areas and equipment selected for review were justified based on failure information, which increases the correctness of the case examples. However, the validity of the results is reduced by differences in human interpretation and human error when performing analyses. The comparison of risk analysis methods, with the help of supplemented SWOT analysis, aims to provide an objective perspective on the advantages and disadvantages of both methods. In addition, what benefits or risks their use in the development of preventive maintenance could cause. Results of supplemented SWOT analyses combine my own experience, perspectives of standards and scientific articles, increasing the reliability of results.

The optimization of preventive maintenance instructions was clearly limited, so the validity of the results is confirmed. The re-determination of preventive maintenance instructions intervals utilized a mathematical and commonly used calculation equation that guarantees results of new intervals to be reliable. However, the determination of equipment failure intervals is based on historical data, and it is not expected that future failures will reoccur on the same cycles. The content changes of preventive maintenance instructions for work description are based on the scientific literature review, my own experience and information provided by maintenance management system about equipment. Scientific literature review and maintenance management system data increase the reliability of optimization results. But in my own experience, the information may be inaccurate or biased, reducing the reliability and validity of results.

The reliability and validity of the thesis are examined using the research questions. The aim of research questions is to solve the research problem with the help of suitable research methods, ensuring the reliability of the results. So, finding a solution to research questions that will increase the reliability of results. The main research question is below: “*What is the reason for the challenges of optimizing preventive maintenance and its plans, and why should the risk analysis methods presented be included in the development of preventive maintenance?”* Challenges in optimizing preventive maintenance plans include identifying their individuality and needs for preventive maintenance required by equipment. So, one right solution is challenging to determine for them. The risk analysis methods presented in the thesis are used to compare the criticalities of equipment and to anticipate possible failure modes, effects and probabilities. The methods facilitate and clarify the planning process and optimization of preventive maintenance.

And the sub-questions are: “*What want to be achieved the optimizing of preventive maintenance instructions and how them will be optimized in the future?”* The aim of optimizing preventive maintenance instructions is to clarify and update partially obsolete current instructions, guaranteeing the need for preventive maintenance required by equipment base. In addition, it is considered whether failures could have been prevented by optimized preventive maintenance actions. Procedure instructions in the results, provide a clear framework for how the instructions should be optimized in the future. *"How can the benefits of new maintenance management system be exploited in the development of preventive maintenance?"* The development and monitoring of preventive maintenance will be significantly facilitated by moving to the new maintenance management system. Novi is more agile and customizable than its predecessor. For example, it becomes easier to edit route maintenance levels, intervals and instructions. The reporting of costs, work performed and work in progress, for example, will also be clarified, creating useful data for decision-makers. Scheduling preventive maintenance actions in the form of a Gantt chart becomes more apparent, and the creation of different measurement bases is made possible.

4.3 Utilization and generalizability of results

The generalizability of results must take into account the individuality of each production facility. So the results cannot be directly generalized to other production facilities in the mill. Equipment are unique and always manufactured separately, so failure modes may vary in different environments. For example, equipment base of steel mill and heavy bar mill are different sizes, and production environment in steel mill is also very dirty, which increases the risk of equipment failure. For example, in the failure information, the bearing failure of roof lift and turning equipment covers most failures in the time period. In a normal situation, failures would not be about as much due to the bearing. In addition, workload of the process and equipment availability can vary, in which case failure modes can vary significantly with different equipment. Therefore, the desired results, such as the need to optimize preventive maintenance instructions, must be determined separately for the equipment of different production facilities. However, the results obtained can be used in the future to check new results obtained and compare them with results of this thesis. Thus, it will be possible to set a framework for the results within which they should fall in the future. However, the methods by which results are obtained can be generalized and utilized in other equipment of the mill. Such as the identification of failures, the use of risk analysis methods and the process of optimizing preventive maintenance instructions.

4.4 The importance of research for the case company

Results of the thesis play a significant role in the development of the case company's operations and maintenance. Thanks to the optimization of preventive maintenance instructions and risk analysis methods, the case company can focus its inspection activities on justified equipment and assess better development targets in its operations. Case company receives a modern and comprehensive theoretical literature review of the current state of maintenance and future trends. There are also different ways and perspectives on how preventive maintenance should be developed in the direction of reliability centered maintenance. Based on the results of the thesis, the company is able to collect, distribute and analyse failure information from different areas and equipment. Research also provides the results of criticality classification and FMEA, as well as the excel templates utilized in them, which can be utilized and generalized to other areas and equipment in the future. Thanks to the optimization of the preventive maintenance instructions, content and intervals for the selected areas have been optimized and updated in the maintenance management system. In addition, new preventive maintenance instructions have been created and old ones have been removed. In addition to theory, methods and results, the development of preventive maintenance in the future is based on procedure instructions that enable case company to unify the optimization of preventive maintenance instructions.

4.5 For the future development

Thesis dealt extensively with different development methods and results for the development of preventive maintenance at the mill. As mentioned above, the thesis provides a “framework” for how preventive maintenance could be developed, but due to the limitation of the thesis, not all possible options could be adequately considered. Listed below are opportunities for further research related to supporting the development of preventive maintenance:

- Regular analysis of failure information (utilization of new information)
- Extensive utilization of risk analysis methods in the development of maintenance
    - Criticality classification, as part of failure information to support preventive maintenance planning
    - FMEA supports in the planning and redefinition of new and existing preventive maintenance instructions
- Continuation of PM instructions optimizations
    - Review all route maintenance levels, inspect content, intervals, equipment, as well remove and create new instructions
    - Bundle and re-sort route maintenance points
    - Consideration of resource adequacy, at the appropriate cost
    - Future use of machine learning and online condition monitoring on critical and failing equipment → predictive maintenance
        - Artificial intelligence supports preventive maintenance planning by identifying, for example, temperature differences, quality defects, production cycles, etc.
    - Compliance with and development of procedure instructions

Among the possibilities for further development, utilization of risk analysis methods and continuation of optimization of preventive maintenance instructions are highlighted. Criticality classification of equipment and failure mode and effects analysis can be used to develop preventive maintenance further, increasing knowledge of the equipment base and prediction of failures. Used excel templates can also be customized to better suit organization needs. Continuing to optimize preventive maintenance instructions will also ensure the need for maintenance required by other equipment in the mill, the correctness of intervals and the adequacy of resources and costs. Therefore, preventive maintenance should be further developed towards predictive maintenance (PdM) using RCM methods. Utilization of real-time condition monitoring in critical equipment. With the help of regular vibration measurements, it is possible to get accurate information about the condition of equipment. There may be more response time than before when a failure of critical equipment is detected before visual signs, such as noise and elevated temperature values. Production time is significantly saved, for example, when spare parts can be ordered before the line breaks and suitable tools and workers can be reserved for maintenance. Thus, the number of downtimes can be effectively reduced by regular measurement cycles or real-time vibration measurement. Utilizing artificial intelligence and machine learning to support preventive maintenance planning can also bring new optimization benefits to maintenance operations. Artificial intelligence methods can be used to predict starting equipment failures through temperature differences and quality defects. In addition, machine learning in collecting and analysing production cycles could be utilized in the future, facilitating preventive maintenance planning.

5. Conclusions

The aim of this thesis was to develop and modernize preventive maintenance of Ovako Imatra steel mill as part of the renewal project of the maintenance management system. The mill's current preventive maintenance plans are partly outdated, in addition to which failures are to be anticipated and prevented by various risk analysis methods. The aim is to reduce failures, identify the most critical equipment and components, and improve mill reliability by optimizing preventive maintenance. Triangulation components are used as research methods; literature review, risk analysis methods and databases of Ovako. In addition to research methods, the thesis utilizes my own experience to achieve results. Thesis is limited to mechanical equipment of steel mill and heavy bar mill.

Thesis determinates the most faulty equipment in the mill based on mechanical failure information. Criticality classification of equipment, as well as failure mode and effects analysis, provide methods to develop preventive maintenance in the direction of reliability centered maintenance (RCM). The optimization of preventive maintenance instructions ensures the need for preventive maintenance of the current equipment base, aiming to correct maintenance intervals and minimize failures. In the results of the thesis, the most faulty areas and equipment were determined for case examples (PSK6800 and FMEA). The most faulty areas were electric arc furnace and 1st rolling stand, and the equipment for roof lift and turning and manipulator equipment. Criticality classification of equipment and FMEA were used to assess the criticality of the most faulty equipment and possible failure modes and their effects. Results of the thesis compare criticality classification of equipment and failure mode and effects analysis with the help of supplemented SWOT analysis. Information from case examples, my own experience and literature review materials were utilized to optimize preventive maintenance instructions. Preventive maintenance instructions were optimized by re-defining intervals, instruction content, object, making new preventive maintenance instructions and removing old unnecessary instructions. Results also provide procedure instructions, how preventive maintenance instructions should be optimized in the future. Optimizations were completed for the new maintenance management system, Pinja Novi.

Among the possibilities for further development, utilization of risk analysis methods and continuation of the optimization of preventive maintenance instructions are highlighted. Criticality classification of equipment and failure mode and effects analysis can be used to develop preventive maintenance further, increasing knowledge of the equipment base and prediction of failures. Continuing to optimize preventive maintenance instructions will also ensure the need for maintenance required by other equipment in the mill, the correctness of intervals and the adequacy of resources and costs. Therefore, preventive maintenance should be further developed towards predictive maintenance (PdM) using RCM methods.

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Appendix 1: Criticality classification for EAF equipment (PSK 6800)

PSK Standardisointi

LAITTEIDEN KRIITTISYYSLUOKITTELU TEOLLISUUDESSA
Criticality Classification of Equipment in Industry

PSK 6800
Liite1
Appendix1

Unit Steel
Object of classification EAF
Prepared by Teemu Havulinna
Version Master's Thesis
Date 22.11.2021

Criticality limit 4000
Weighting factor of production loss Wp 36

Identifier of object	Name of object	Time between failures (1…8)	Safety risks (0…16)	Environ-mental risks (0…16)	Production loss (0…4)	Quality costs (0…4)	Repair costs (0…4)	Criticality index	Criticality sub-indexes				
		Weighting W -->	30	20	36	30	20	K	Ks	Ke	Kp	Kq	Kr
SU0715	Holvin kääntö	8	8	4	4	2	4	4832	1920	640	1152	480	640
SU0721	Virtaköydet	8	8	2	3	1	4	3984	1920	320	864	240	640
SU0729	EAF-uuni vesijäähdytysjärjestelmä	8	4	4	3	1	2	3024	960	640	864	240	320
SU0735	Hiili-injektori	4	2	4	3	2	2	1392	240	320	432	240	160
SU0736	Kalkki-injektori	4	2	4	3	2	2	1392	240	320	432	240	160
-	EAF-uuni muut komponentit	4	4	2	3	1	2	1352	480	160	432	120	160
SU11	Suodinlaitos	4	2	8	1	1	2	1304	240	640	144	120	160
SU0733	Lanssimanipulaattori	2	2	2	3	1	2	556	120	80	216	60	80
SU0717	Elektrodiarmit	1	4	4	3	2	3	428	120	80	108	60	60
SU0727	Hydrauliikka	1	2	8	1	1	2	326	60	160	36	30	40
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0

Appendix 2: Criticality classification for 1st rolling stand equipment and strapping machines (PSK 6800)

PSK Standardisointi

LAITTEIDEN KRIITTISYYSLUOKITTELU TEOLLISUUDESSA
Criticality Classification of Equipment in Industry

PSK 6800
Liite1
Appendix1

Unit Heavy rolling
Object of classification 1st rolling stand and strapping machines
Prepared by Teemu Havulinna
Version Master's Thesis
Date 23.11.2021

Criticality limit 3000
Weighting factor of production loss Wp 24

Identifier of object	Name of object	Time between failures (1…8)	Safety risks (0…16)	Environ-mental risks (0…16)	Production loss (0…4)	Quality costs (0…4)	Repair costs (0…4)	Criticality index	Criticality sub-indexes				
		Weighting W -->	30	20	24	30	20	K	Ks	Ke	Kp	Kq	Kr
KV0965	Manipulaattorit (koukkukääntäjät + hydrauliikkakääntäjät)	8	8	2	2	2	4	3744	1920	320	384	480	640
KV1521	Sitomakone, arina 3.	8	4	2	3	1	3	2576	960	320	576	240	480
KV151817	Profiilisitomakoneet	8	4	2	3	1	3	2576	960	320	576	240	480
KV0933	Valssit + Kytkimet	4	8	2	3	2	4	1968	960	160	288	240	320
KV0946	Etusiirtolaite (lopikat)	4	8	2	2	1	2	1592	960	160	192	120	160
KV09	Voitelulaitteisto	4	2	8	1	1	2	1256	240	640	96	120	160
KV0959	Takatyörullarata	2	8	4	2	1	3	916	480	160	96	60	120
KV0929	Etutyörullarata	2	8	4	2	1	3	916	480	160	96	60	120
KV0905	Tulorullarata (pesurilta-etutyörullille)	2	8	4	2	1	3	916	480	160	96	60	120
KV0977	Jäähdytysvedet	2	2	8	1	2	1	648	120	320	48	120	40
KV0941	Chester (vaihdelaatikko)	2	2	2	3	0	4	504	120	80	144	0	160
KV0953	Valssimoottori + Tyrak	1	2	2	3	0	4	252	60	40	72	0	80
KV0003	Asennusnosturi 25 / 6,3 t	1	2	0	2	0	3	168	60	0	48	0	60
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0

Appendix 3: Failure mode and effects analysis for roof lift and turning equipment

OVAKO

Failure Mode and Effects Analysis FMEA, Maintenance

Author: TMH

Area / Equipment	Actor(s)	Department	Date	Acceptor	Updated
Steel / EAF	Teemu Havulinna	KP	24.11.2021		7.12.2021

Equipment ID	Equipment	Component	Failure mode	Locally: Effect of failure	Other process: Effect of failure	Severity (1-10)	Cause of failure	Occurance (1-10)	Controls to detect failure	Detection (1-10)	RPN	Improvement: Recommended action(s)	Responsibility	Schedule	Result after actions: Implemented action(s)	Completion period	Severity (1-10)	Occurance (1-10)	Detection (1-10)	RPN
SU0715	Holvin kääntö														0					
		Päälaakeri	Adhesiivinen kuluminen	Hidastaa holvin käännön toimintaa	Vaikuttaa koko sulatusprosessiin	10	-Voitelun puute -Suuret voimat	2	EH-kierrokset	7	140	-On-line kunnonvalvonta (Schaeffler/SKF) -Optimoitu voiteluhuolto	N.N.	2022	-On-line kunnonvalvonta (Schaeffler/SKF) -Optimoitu voiteluhuolto	2022	10	1	3	30
		Lukituslaite	Väsyminen	Hidastaa holvin käännön toimintaa	Vaikuttaa koko sulatusprosessiin	5	-Kuormitukset niveliin ja kiinnityksiin	6	EH-kierrokset	3	90	-Puhdistukset -Komponettien säännöllinen vaihto	N.N.	2022	-Puhdistukset -Komponettien säännöllinen vaihto	2022	5	5	1	25
		Liitokset ja kiinnitykset	Väsyminen ja löystyminen	Hidastaa holvin käännön toimintaa	Vaikuttaa koko sulatusprosessiin	4	-Tärinä -Voimat	7	-EH-kierrokset -Vuosihuolto	3	84	-Vaimennusmateriaalien käyttö -Säännölliset tarkastukset ja kiristykset	N.N.	2022	-Vaimennusmateriaalien käyttö -Säännölliset tarkastukset ja kiristykset	2022	4	5	1	20
		Nostokara	Adhesiivinen kuluminen	Hidastaa holvin noston toimintaa	Vaikuttaa koko sulatusprosessiin	7	-Voitelun puute -Suuret voimat	4	EH-kierrokset	3	84	-Puhdistukset -Optimoitu voiteluhuolto	N.N.	2022	-Puhdistukset -Optimoitu voiteluhuolto	2022	7	3	1	21
		Runkorakenne	Väsyminen	Suuri turvallisuusriski	Pysäyttä pahimmillaan koko sulatuksen	6	-Suuret voimat ja momentit	4	-EH-kierrokset -Vuosihuolto	3	72	-Puhdistukset -Rakenteen silmämääräinen tarkistus	N.N.	2022	-Puhdistukset -Rakenteen silmämääräinen tarkistus	2022	6	4	1	24
		Hydrauliikkajärjestelmä	Vuoto	Aiheuttaa sylinterin toimimattomuuden	Holvin kääntö ei toimi	4	Vuoto tiivisteissä, letkuissa tai liittimissä	4	-EH-kierrokset -Vuosihuolto	3	48	-Hydrauliikkajärjestelmän seuranta -Sylinterien säännöllinen vaihto	N.N.	2022	-Hydrauliikkajärjestelmän seuranta -Sylinterien säännöllinen vaihto	2022	4	4	1	16
		Tukipyörä	Kuluminen	Hidastaa holvin käännön toimintaa	Vaikuttaa koko sulatusprosessiin	5	-Epäpuhtaudet -Suuret voimat	3	EH-kierrokset	3	45	-Puhdistukset -Komponenttien säännölliset vaihdot	N.N.	2022	-Puhdistukset -Komponenttien säännölliset vaihdot	2022	5	3	1	15

Appendix 4: Failure mode and effects analysis for manipulator

OVAKO

Failure Mode and Effects Analysis FMEA, Maintenance

Author: TMH

Area / Equipment	Actor(s)	Department	Date	Acceptor	Updated
Heavy rollng/ 1st rolling pair	Teemu Havulinna	KP	2.12.2021		7.12.2021

Equipment ID	Equipment	Component	Failure mode	Effect of failure (Locally)	Effect of failure (Other process)	Severity (1-10)	Cause of failure	Occurance (1-10)	Controls to detect failure	Detection (1-10)	RPN	Improvement: Recommended action(s)	Responsibility	Schedule	Result after actions: Implemented action(s)	Completion period	Severity (1-10)	Occurance (1-10)	Detection (1-10)	RPN
KV0965	Manipulaattori																			
		Kannatuspyörästö	Hauras murtuma	Ohjainten toiminta keskeytyy	Valssaaminen epäonnistuu	6	Kohdistuvat voimat	6	-EH-kierrokset -Vuosihuolto	7	252	-Puhdistukset -Kuluvien osien/rakenteen tarkastus ja vaihto	N.N.	2022	-Puhdistukset -Kuluvien osien/rakenteen tarkastus ja vaihto	2022	6	4	5	120
		Työntökoneisto	Laakerivaurio	Ohjainparin toiminta keskeytyy	Valssaaminen epäonnistuu	4	-Epäpuhtaudet -Kohdistuvat voimat	6	EH-kierrokset	7	168	-On-line kunnonvalvonta -Puhdistukset	N.N.	2022	-On-line kunnonvalvonta -Puhdistukset	2022	4	5	3	60
		Ohjainlaatan komponentit	Adhessiivinen kuluminen	Ohjainten toiminta vaikeutuu	Valssaaminen hidastuu	5	Edestakainen liike	6	EH-kierrokset	5	150	-Puhdistukset -Säännölliset komponenttien vaihdot	N.N.	2022	-Puhdistukset -Säännölliset komponenttien vaihdot	2022	5	4	3	60
		Lamellikytkin	Adhessiivinen kuluminen	Ohjainparin toiminta keskeytyy	Valssaaminen epäonnistuu	6	Kohdistuvat voimat	3	EH-kierrokset	7	126	-Kytkimen kunnon tarkastaminen -Säännöllinen vaihtaminen	N.N.	2022	-Kytkimen kunnon tarkastaminen -Säännöllinen vaihtaminen	2022	6	2	5	60
		Koukkukääntäjä	Adhessiivinen kuluminen	Valssaaminen hidastuu	Hidastaa koko KV toimintaa	6	Kohdistuvat voimat	4	-EH-kierrokset -Vuosihuolto	5	120	-Kuluvien osien tarkastus -Puhdistukset	N.N.	2022	-Kuluvien osien tarkastus -Puhdistukset	2022	6	3	3	54
		Kiskosto	Abrassiivinen kuluminen	Ohjainten toiminta vaikeutuu	Valssaaminen hidastuu	7	Edestakainen liike	5	-EH-kierrokset -Vuosihuolto	3	105	-Puhdistukset -Kuluvien osien tarkastus ja vaihto	N.N.	2022	-Puhdistukset -Kuluvien osien tarkastus ja vaihto	2022	7	4	1	28
		Etuohjain	Abrassiivinen kuluminen	Valssaaminen hidastuu	Hidastaa koko KV toimintaa	6	Epäpuhtaudet	3	-EH-kierrokset -Vuosihuolto	5	90	-Puhdistukset -Kuluvien osien tarkastus ja vaihto	N.N.	2022	-Puhdistukset -Kuluvien osien tarkastus ja vaihto	2022	6	2	3	36
		Takaohjain	Abrassiivinen kuluminen	Valssaaminen hidastuu	Hidastaa koko KV toimintaa	6	Epäpuhtaudet	3	-EH-kierrokset -Vuosihuolto	5	90	-Puhdistukset -Kuluvien osien tarkastus ja vaihto	N.N.	2022	-Puhdistukset -Kuluvien osien tarkastus ja vaihto	2022	6	2	3	36
		Hydrauliikkajärjestelmä	Vuodot	Ohjainparin toiminta keskeytyy	Valssaaminen epäonnistuu	4	Ikääntyneet ja epälaadukkaat komponentit	6	EH-kierrokset	3	72	Säännölliset komponenttien vaihdot	N.N.	2022	Säännölliset komponenttien vaihdot	2022	4	5	1	20
		Jäähdytysvesijärjestelmä	Eroosio	Kuuma teräs kuormittaa laitteita ilman jäähdytystä	Laitteiden vikaantumiset lisääntyy	4	Ikääntyneet ja epälaadukkaat komponentit	6	EH-kierrokset	3	72	Säännölliset komponenttien vaihdot	N.N.	2022	Säännölliset komponenttien vaihdot	2022	4	5	1	20
		Moottoripeti	Pinnan väsyminen	Moottorin linjausvirhe	Kuormittaa jarrua ja vaihdetta	5	Väännön aiheuttama rasitus	3	EH-kierrokset	3	45	-Pedin säännöllinen tarkastus -Linjauksen tarkastus	N.N.	2022	-Pedin säännöllinen tarkastus -Linjauksen tarkastus	2022	5	3	1	15
		Takavasteet	Pinnan väsyminen	Ohjainten toiminta vaikeutuu	Valssaaminen hidastuu	6	Kohdistuvat voimat	2	EH-kierrokset	3	36	-Rakenteen tarkastukset -Vasteiden säännöllinen vaihto	N.N.	2022	-Rakenteen tarkastukset -Vasteiden säännöllinen vaihto	2022	6	2	1	12

Appendix 5: Optimization of preventive maintenance intervals for EAF and 1st rolling stand equipment

Redefining intervals

(reference: kunnossapito, tuotanto-omaisuuden hoitaminen, Järviö 2017)

Equation:
T (interval) = 2 x unavailability x MTBF
Interval rounding down !!

Equipment	Name	Mech. Insp.	Lubrication	Current interval [week]	Line numbe	Work description	Unavailability	MTBF [week]	Optimized interval T [week]
Steel / EAF									
SU0715	**Holvin kääntö**								
		MKJ60		**4**	24591	HOLVIN KÄÄNTÖ-JA NOSTOLAITTEET | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: -holvin esikääntö/pääkääntö: -sylinterit,sylinterien kiinnitykset ja putket. - lukituslaitteen nivelet. - lukituslaitteen sylinterit,sylinterien kiinnitykset ja letkut. - laakerointi ja voitelu putket. - laakerin alapuolen siisteys (rasva/öljy aiheuttaa palovaaran) - rajakatkaisijat - holvin nosto: - sylinteri,sylinterin kiinnitys ja letkut. - johteet ja ohjauspyörä. - rajakatkaisijat PÄIVITETTY 4.11.2014 JLn	**0,04**	**26**	**2,08**
		MKJ60		**8**	51354	HOLVIN KÄÄNTÖ-JA NOSTOLAITTEET | Tarkastusjakso 8 vko. Tarkastukseen kuuluu: - lukituslaitteiden suojan irroitus ja sisäpuolen puhdistus	**0,04**	**52**	**4,16**
SU0721	**Virtaköydet**								
		MKJ60			24557	VIRTAKÖYDET | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: -virtaköydet ja mahdolliset alkavat tai olemassa olevat repeytymiset/kulumiset. Päivitetty 3.1.2022 TMH	**0,04**	**52**	**4,16**
SU07291	**EAF-uuni vesijäähdytysjärjestelmä**								
		MKJ60			24072	VESIJÄÄHDYTYSJÄRJESTELMÄ | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: - seinäpaneeleiden syöttövesiletkut. - muut putket ja letkut. PÄIVITETTY 22.12.2021 TMH	**0,04**	**52**	**4,16**
SU0741	**Pohjahuuhtelulaitteet**								
		MKJ60			24619	POHJAHUUHTELULAITTEET | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: -pohjahuuhtelu letkujen ja putkien tarkastus. Päivitetty 5.1.2022 TMH	**0,04**	**52**	**4,16**
SU073501	**Hiili-injektori (Stein)**								
		MKJ60			24496	STEIN HIILILÄHETIN JA PUTKISTO | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: - venttiilien toiminnan tarkastus. - sylinterit ja sylinterien kiinnitykset. - hyd. letkut ja putket. - tukosten havaitseminen ja raportointi. Päivitetty 5.1.2022 TMH	**0,04**	**52**	**4,16**
SU073601	**Kalkki-injektori (Stein)**								
		MKJ60			24492	STEIN KALKKILÄHETIN JA PUTKISTO | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: - venttiilien toiminnan tarkastus. - sylinterit ja sylinterien kiinnitykset. - hyd. letkut ja putket. - tukosten havaitseminen ja raportointi. Päivitetty: 27.12.2021 TMH	**0,04**	**52**	**4,16**
Heavy rolling mill / 1st rolling stand									
KV0965	**Manipulaattorit (koukkukääntäjät + hydrauliikkakääntäjät)**								
		VKJ75			2581	KV:n manipulaattorit, hydrauliikka | Tarkastusjakso 2 vko. Manipulaattori alueen kaikkien hydrauliikkasylinterien, -letkujen, -putkien, -liitosten tarkastaminen.	**0,04**	**26**	**2,08**
		VKJ75		**4**	2580	KV:n manipulaattorit,käyttökoneisto | Tarkastusjakso 4 vko. KV:n manipulaattorin käyttökoneiston EH-tarkastus. Tarkastukseen kuuluu: -vaihde,joustavakytkin ja moottorin kiinnitys. -väliakselit tukilaakerit,hammaspyörät ja näiden kiinnitys	**0,04**	**26**	**2,08**
			VKJ86	**12**	2583	KV:n manipulaattorit,pyörästöt | Voitelujakso 12 vko. KV:n manipulaattorin pyörästöjen voiteluhuolto. Tehtäviin kuuluu: -kannatuspyörät ja ohjauspyörästöt nippavoitelu. 160566.	**0,04**	**104**	**8,32**
			VKJ86	**24**	2585	KV:n manipulaattorit,käyttökoneisto | Voitelujakso 24 vko. KV:n manipulaattorin käyttökoneiston voiteluhuolto. Tehtäviin kuuluu: -vaihde öljyjen tarkastus. 160412 -väliakselit tukilaakerit nippavoitelu. 160566	**0,04**	**156**	**12,48**
			VKJ86	**156**	2586	KV:n manipulaattorit,käyttökoneisto | Voitelujakso 156 vko. KV:n manipulaattorin käyttökoneiston voiteluhuolto. Tehtäviin kuuluu: -vaihde öljyjen vaihto. 160412	**Havulinna Teemu:** Recommendation for interval		**104**
KV1901	**Etusiirtolaite (lopikat)**								
		VKJ75		**4**	3529	Etuvetolaite käyttökoneisto | Tarkastusjakso 4 vko. Etuvetolaitteen käyttökoneiston EH-tarkastus. Tarkastukseen kuuluu: -köydet,köysien kiinnitys ja "köysien kireys". -siirtovaunut,vaunujen pyörät,vetovaijeriin kiinnitys, siirtäjät ja vaunujen rungot. -hellalevyt ja hellalevyjen "paikallaan olo"	**0,04**	**26**	**2,08**
		VKJ75		**12**	3531	Etuvetolaite käyttökoneisto | Tarkastusjakso 12 vko. Etuvetolaitteen käyttökoneiston EH-tarkastus. Tarkastukseen kuuluu: -vaihde,vaihteen kiinnitys. -käyttöakseli,laakerit,köysirummut ja kytkimet. -taittopyörä,taittopyörän laakerointi,keinu ja säätölaitteet. -hammasvaihdemoottori,kytkin ja näiden kiinnitykset	**0,04**	**52**	**4,16**
KV09	**Voitelulaitteisto**								
		VKJ75			2550	KV:n hydrauliikkahuoneet | Tarkastusjakso 4 vko. Tarkastukseen kuuluu: - KV hydrauliikkahuoneiden tarkastus. - letkut, putket, liittimet, venttiilit. - epäpuhtauksista raportointi.	**0,04**	**52**	**4,16**

Appendix 6: Procedure instructions for the future – Work instructions

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Preventive maintenance - Work instructions

Structure and filling of route maintenance plans (Pinja Novi)

This work instruction to the structure and filling of maintenance plans for the new maintenance system. Maintenance plans consist of calendar maintenance and route maintenance. Calendar maintenance always creates a new work order and can include various measurements. Route maintenance consists of different route maintenance points and they form a work package depending on the maintenance intervals. This work instruction examines the route maintenance of mechanical maintenance.

Maintenance plans for the most critical and important areas/equipment should be optimized or planned first. The following steps or risk assessment tools should be used to identify the most critical areas/equipment:

1. Determination of the most faulty areas/equipment (e.g. Promas failure information)
2. Criticality classification of equipment (PSK 6800)
3. Failure mode and effect analysis (FMEA)

By completing these steps, you can identify the most critical and important areas/equipment.

Structure of the route maintenance plan:

- Route maintenance is divided into route maintenance levels based on Powermaint maintenance plans (e.g. JJH60, etc.)
- The route maintenance level includes e.g. route maintenance name, orderer, maintenance group, author, work type, interval, duration and next generation date.
- Route maintenance is divided into different work packages based on interval, i.e. maintenance interval. The work packages still consist of different maintenance points for route maintenance, i.e. actual preventive maintenance work. (Figure 1.)
- Route maintenance points include, for example, line number, equipment hierarchy, work description and hour estimate.

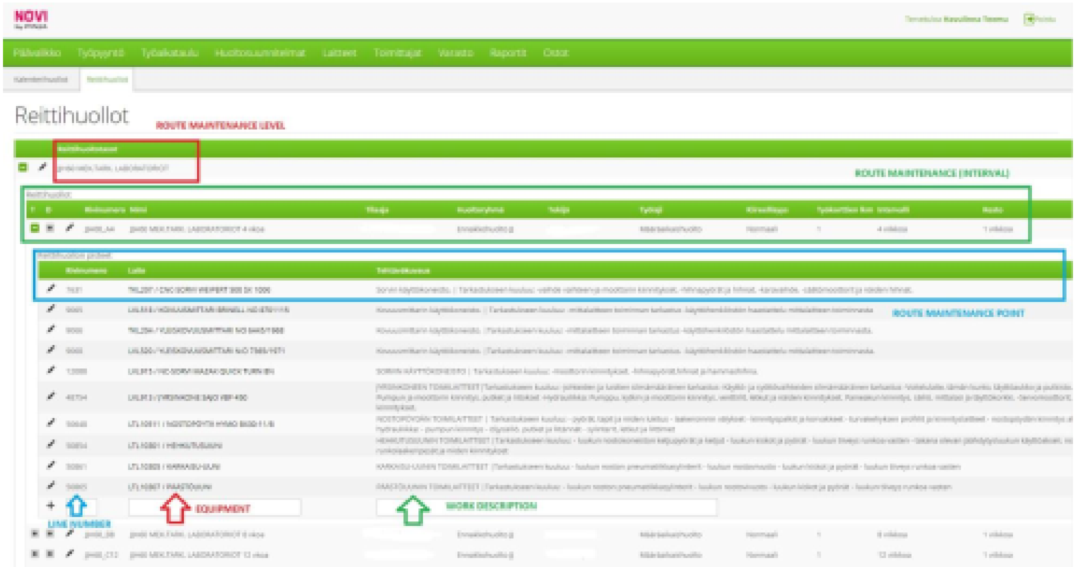

Figure 1. Different route maintenance levels

Instructions for filling in the route maintenance plan (new route maintenance level, route maintenance (interval) or route maintenance point creation):

1) Complete the required information, i.e.:
   a) Route maintenance level
      i) Maintenance level "code" and name
   b) Route maintenance (interval)
      i) Line number, name, orderer, maintenance group, author, work type, priority, number of work order (1), interval, duration, next generation date, transfer (if applicable)
   c) Route maintenance point
      i) Line number, equipment, work description, create work order (selected), hour estimate

2) Save data from the "+" icon

3) You can add documents via the "D" icon

4) You can edit existing route maintenance levels, route maintenance, and route maintenance points from to " " icon

5) Finally, when creating a new route maintenance (interval), it must be generated, pressing the "0" icon to turn the icon green to "1". In this case, route maintenance is also visible in the work schedule.

Instructions for filling in the work description:

The following structure should be followed when modifying/creating work descriptions for route maintenance points:

1. The name of the maintenance object, i.e. the equipment.
2. "|" to distinguish between the name of the equipment and the next item.
3. "Inspection interval x week."
4. Tell what is included in the maintenance. Briefly, but accurately.
5. For end "UPDATED xx.xx.20xx INITIALS"

Example of a good work description:

"ROOF LIFT AND TURNING EQUIPMENT, FRAME | Inspection interval 12 week.
The inspection shall include:
- roof lifting and turning:main turning/pre-turning devices
- cylinders, cylinder fastenings and pipes.
- steel structures
- covers, screens, hatches and their attachments.
- limit switches. Updated 10.01.2022 TMH "