



**DEVELOPMENT OF PREVENTIVE MAINTENANCE REPORTING  
FRAMEWORK IN LARGE-SCALE INDUSTRY COMPANY**

Lappeenranta–Lahti University of Technology LUT

Master's programme in Industrial Engineering and Management

2024

Jarno Taskinen

Examiners: Docent, post-doctoral researcher Lasse Metso

University lecturer Tiina Sinkkonen

## ABSTRACT

Lappeenranta–Lahti University of Technology LUT

School of Engineering Sciences

Industrial Engineering and Management

Jarno Taskinen

### **Development of preventive maintenance reporting framework in large-scale industry company**

Master's thesis

2024

63 pages, 21 figures, 4 tables and 8 appendices

Examiners: Docent, post-doctoral researcher Lasse Metso

University lecturer Tiina Sinkkonen

Keywords: preventive maintenance, business intelligence, reporting, performance measurement, key performance indicator, design thinking

Today's highly competitive market environment creates a lot of pressure for the industrial companies to be more and more cost effective. Plant maintenance costs present a significant share of the total production costs. Effective maintenance is essential for maximizing equipment uptime, reducing production costs and ensuring a safer working environment in industrial plants. Preventive maintenance, as one of the maintenance types, plays crucial role in minimizing the equipment failures and optimizing the overall costs.

The objective of this study was to develop a preventive maintenance reporting framework, which enables enhancement and optimization of preventive maintenance operations in a research company which operates in large-scale industry. This study consisted of a literature review and action research in the research company. Action research included a comprehensive requirement gathering and reporting framework development through the workshops in strong collaboration with the research company representatives. The reporting framework development was conducted by utilizing design thinking as a methodology.

As a result of this study, future preventive maintenance reporting framework was developed and defined for the research company. The results are presented through the visualized mock-ups which illustrate the future preventive maintenance reporting solution. By adhering to this framework, the research company can implement the concrete reporting solution for preventive maintenance as a one part of the maintenance reporting system using business intelligence tools.

## TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Teknis-luonnontieteellinen

Tuotantotalous

Jarno Taskinen

### **Ennakoivan kunnossapidon raportointikehyksen kehittäminen suurteollisuuden yrityksessä**

Tuotantotalouden diplomityö

2024

63 sivua, 21 kuvaa, 4 taulukkoa ja 8 liitettä

Tarkastajat: Dosentti, tutkijatohtori Lasse Metso

Yliopisto-opettaja Tiina Sinkkonen

Avainsanat: ennakoiva kunnossapito, business intelligence, raportointi, suorituskyvyn mittaaminen, suorituskykymittari, design thinking

Nykyinen erittäin kilpailtu markkinaympäristö asettaa teollisuusyrityksille paljon paineita olla entistä kustannustehokkaampia. Tehtaiden kunnossapitokustannukset muodostavat merkittävän osan tuotannon kokonaiskustannuksista. Tehokas kunnossapito on tärkeässä roolissa laitteiden käyttöajan maksimoinnissa, tuotantokustannusten vähentämisessä ja turvallisemman työympäristön varmistamisessa teollisuuslaitoksissa. Ennakoiva kunnossapito yhtenä kunnossapidon tyyppinä on keskeisessä roolissa laitteiden vikojen minimoimisessa ja kokonaiskustannusten optimoinnissa.

Tämän tutkimuksen tavoitteena oli kehittää ennakoivan kunnossapidon raportointikehys, jonka avulla ennakoivaa kunnossapitoa voidaan tehostaa ja optimoida suurteollisuudessa toimivassa yrityksessä. Tutkimus koostui kirjallisuuskatsauksesta ja toimintatutkimuksesta. Toimintatutkimus koostui kattavasta vaatimusmäärittelystä ja raportointikehyksen kehittämisestä, joka toteutettiin työpajoissa tiiviissä yhteistyössä yrityksen edustajien kanssa. Raportointikehyksen kehittämisessä hyödynnettiin design thinking -menetelmää.

Tämän tutkimuksen tuloksena kehitettiin ja määritettiin ennakoivan kunnossapidon raportointikehys tutkimusyriykselle. Noudattamalla luotua raportointikehystä tutkimusyritys voi toteuttaa ennakoivan kunnossapidon raportointiratkaisun osana yrityksen kokonaisvaltaista kunnossapitoraportointijärjestelmää käyttäen business intelligence -työkaluja.

## ACKNOWLEDGEMENTS

The last four years have been such a learning experience for me, and the journey comes to an end with this master's thesis. These studies have provided me a lot of insights and opened new opportunities in my career. I have been fortunate to integrate and combine my work and studies, as they have complemented each other exceptionally well. Of course, the combination has not been always the easiest thing, and it has required long days and persistence.

I would like to express my gratitude to LUT University and its personnel for the flexible studying possibilities, high-quality teaching and well-designed degree program.

Last but certainly not least, thank you Reetta. Your support and encouragement have been invaluable.

Lappeenranta, 29<sup>th</sup> October 2024

Jarno Taskinen

## Table of contents

Abstract

Acknowledgements

1	Introduction .....	9
1.1	Background of the study .....	9
1.2	Research objectives and scope .....	10
1.3	Research methodology .....	11
1.4	Structure of the thesis .....	13
2	Maintenance .....	14
2.1	Industrial plant .....	14
2.2	Maintenance fundamentals.....	15
2.3	Preventive maintenance .....	18
2.4	Maintenance information systems.....	20
2.5	Basic reporting in maintenance .....	23
3	Preventive maintenance performance.....	25
3.1	Preventive maintenance performance measurement.....	25
3.2	Preventive maintenance success factors.....	27
3.3	Role of business intelligence.....	29
4	Action research: development of preventive maintenance reporting framework .....	32
4.1	Organization and needs .....	32
4.2	Methodologies.....	34
4.3	Workshop implementation .....	38
4.4	Preventive maintenance reporting framework .....	46
5	Conclusions .....	54
5.1	Summary .....	54
5.2	Answering the research questions .....	54
5.3	Limitations and future research suggestions .....	57
	References.....	59

## **Appendices**

Appendix 1. Key info of the first workshop

Appendix 2. Key info of the second workshop

Appendix 3. Key info of the third workshop

Appendix 4. Key info of the fourth workshop

Appendix 5. Key info of the full team review

Appendix 6. Key info of the finalization meeting

Appendix 7. Preventive maintenance planning – initial notes and question list

Appendix 8. Preventive maintenance execution – initial notes and question list

## Figures

Figure 1: Input – output diagram of the research

Figure 2: An industrial plant modelled as a hierarchy of parts

Figure 3: Generic process flow of a production plant

Figure 4: Maintenance types

Figure 5: Bathtub curve

Figure 6: The role of maintenance information system

Figure 7: Simplified figure of maintenance management system's general functions and features

Figure 8: Compiled information enables informed decision-making

Figure 9: Kemmis's interpretation of Kurt Lewin's model of action research

Figure 10: A design thinking process

Figure 11: The design process and cycle of design thinking

Figure 12: Requirement gathering structure

Figure 13: First version of the graph

Figure 14: Second version of the graph

Figure 15: Final version of the graph

Figure 16: Preventive maintenance – Planning – Master data

Figure 17: Preventive maintenance – Planning – Maintenance plan management

Figure 18: Preventive maintenance – Planning – Maintenance plan history

Figure 19: Preventive maintenance – Execution – Main page

Figure 20: Preventive maintenance – Execution – Orders

Figure 21: Preventive maintenance – Execution – Notifications

**Tables**

Table 1: SMART criteria for KPI quality evaluation

Table 2: The core group representatives

Table 3: The reference group representatives

Table 4: Theory and empirical study comparison

# 1 Introduction

This chapter serves as an introduction to this master's thesis. It provides background information about the study, study's objectives and defined scope. It also provides information about the research methodologies employed and describes the structure of the thesis.

## 1.1 Background of the study

Purpose and objective of maintenance in industrial production plants (later industrial plant) is to maximize running time as cost-effectively as possible (Duffuaa & Raouf 2015, 223). Effective maintenance is crucial for maximizing equipment uptime, reducing production expenses, and ensuring a safer working environment (Sigsgaard et al. 2021, 1).

In manufacturing industry, maintenance usually creates a significant share of the total production costs in industrial plants. Various studies over the years have presented estimates of the maintenance costs of the total production costs. Maggard and Rhyne (1992) state that maintenance costs can represent 10-40 percent of the company's production cost. According to Bevilacqua and Braglia (2000), maintenance costs can range from 15 to 70 percent of the total production cost and Coetzee (2004) states that it can vary between 15 to 50 percent. As a conclusion, studies show that maintenance costs are unquestionably significant in the industrial plants.

Despite of the significance of the maintenance for the high-performing industrial plant; maintenance has not always received much of an attention. Nyman and Levitt (2001) state that in general within most organizations, the battle for funding is highly competed and maintenance has two strikes in the debate. First, it is poorly understood function and therefore underappreciated. Second, it does not contribute to the "bottom line" meaning it does not generate any earnings. Traditionally, companies have seen maintenance as a necessary evil (Mobley 2004, 1-2).

However, today's highly competitive market environment creates a lot of pressure for companies' performance. Here, interest towards maintenance and its optimization is

growing. Industrial companies must prioritize safety, environment, energy efficiency and profitability to a greater extent. Attention towards maintenance has increased together with this general development. In addition, maintenance has faced major developments over the years due to increased attention and advanced technical capabilities. (Deepak Prabhakar & Dharmaraj 2018, 791; Sigsgaard et al. 2021, 1)

This research was completed in a global renewable materials company (later company or research company). In the company, maintenance performance has been measured and improved already for years with different business intelligence and reporting solutions. However, there is on-going major change and development in the company's business intelligence system which gives a great opportunity to review the current business needs for the maintenance reporting requirements and based on the requirements, develop a new maintenance reporting solution for the company. As part of the preparation for this change project, there had been concluded a pre-study of the receding reporting system in the end of year 2023. Pre-study presented the current state of the maintenance reporting and highlighted the challenges and future needs for the reporting. The most important areas for improvement are the usability, consistency, and comprehensibility of the reports. Other issue is the data quality, which means there has been identified some data related errors and problems. This pre-study served as a catalyst for this research. In this study, some aspects from the pre-study are brought up, but since it is not in the primary focus of this research, it is not presented in detail.

## 1.2 Research objectives and scope

As part of the company's reporting system development, this study focuses on one area of the future maintenance reporting solution: preventive maintenance reporting. Furthermore, this study is scoped to gather and define the requirements for the preventive maintenance reporting and develop a framework and definitions for the future development of preventive maintenance reporting in the company.

Maintenance, reporting, performance measurement and business intelligence related literature provide a solid base for the study. Empirical study in the company, with company's key maintenance representatives specifies and deepens the framework from the industry and company's point of view. Theoretical basis combined with completed empirical study results

to a holistic framework for the company's future preventive maintenance reporting. The key maintenance representatives define the business requirements for the future solution. Purpose of the framework is to provide guidelines for the preventive maintenance reporting practical implementation in the company. Overall objective is to improve company's situational awareness of the preventive maintenance performance and its development through business intelligence. Although this study is focusing only to the preventive maintenance reporting framework, it is important to emphasize that preventive maintenance reporting will be just one part of the company's comprehensive maintenance reporting solution.

The research questions of the study can be defined with two following questions:

- RQ1: What are the key success factors in preventive maintenance?
- RQ2: What are the research company's requirements for the preventive maintenance reporting?

Goal of the study is to create a framework for preventive maintenance reporting which supports company's industrial plants to manage and improve their preventive maintenance operations. This research provides only the framework and implementation plan for the company's future preventive maintenance reporting. This does not consider the actual implementation of the data models and preventive maintenance reporting in the company.

### 1.3 Research methodology

This study can be structurally divided into two: a literature review and action research in the company.

#### **Literature review**

In the literature review, integrative review approach was chosen to be applied. Integrative literature review is a comprehensive and holistic approach in reviewing the literature and aims to synthesise findings from multiple studies and sources. The purpose of applying an integrative review approach is to offer an overview of the existing knowledge base, conduct a critical analysis, and potentially re-conceptualize and possibly expand the theoretical knowledge base the topic as it evolves. (Snyder 2019, 335–336)

The integrative review approach fits well for this study and its research questions because of the need for comprehensive and holistic understanding of the topic, critical analysis of the different studies and sources, and inclusiveness as the topic of preventive maintenance reporting is multidisciplinary and requires a broad and inclusive perspective.

The literature review was conducted using scientific articles, journals and books found through academic library search engine Primo of Lappeenranta University of Technology (LUT), Scopus, Science Direct and Springer Link. The main key words used in the searches were “maintenance”, “plant maintenance”, “preventive maintenance”, “production plant”, “maintenance fundamentals”, “maintenance performance”, “preventive maintenance performance”, “preventive maintenance plan”, “preventive maintenance planning”, “performance measurement”, “maintenance information system”, “business intelligence”, “action research”, “design thinking” and “workshop research method”.

### **Action research**

In the empirical part of the study, action research was chosen to be applied. In this study, it is essential to conduct research in collaboration with the organization. Action research is all about people interacting together and learning in the process to be able to take purposeful action to improve a thing (McNiff 2013, 25). Collaboration and essential information gathering were done in the workshops with company’s representatives. Workshops and design thinking were employed as the methods in the action research. Workshops offered the environment for applying the design thinking process. There were four two-hour workshops with two company’s maintenance key representatives. Workshops were implemented in a way that they supported the design thinking process. Workshops were mainly focusing the ideation, generation of insights and gathering the requirements. Between the workshops, researcher prepared and progressed the prototypes and low-fidelity mock-ups of the future solution based on the inputs given by the representatives. After the workshops, preliminary mock-ups as the result were presented in the full team review for the reference group of 20 maintenance representatives, enabling them provide feedback for the improvements. Finally, there was a closing workshop with the key representatives where the mock-ups were finalized and signed off.

## 1.4 Structure of the thesis

The structure of the thesis is presented in the Figure 1 which includes sources, chapters and outcomes of this thesis.

Thesis begins with the theory focused chapters 2-3. Chapter 2 includes general introduction to maintenance in large scale industry. It gives an understanding for a reader about maintenance in general, different types of maintenance, importance of maintenance for the manufacturing company's competitiveness as well as maintenance information systems and their basic reporting. In the chapter 3, the focus is on the preventive maintenance performance: what is performance measurement, what are the success factors in preventive maintenance and how business intelligence can support in obtaining situational awareness of preventive maintenance performance through data.

After dealt with the foundational theory in relation with the study's scope, the empirical action research in the research company is presented in the chapter 4. It consists of an introduction of the research company and its operating environment, the pre-study description as a starting point for this study, research methodologies, workshop implementation and developed preventive maintenance reporting framework. Thesis is concluded in the chapter 5 which summarizes the study, answers to the research questions and discuss the future research. Figure 1 illustrates the structure of this thesis.

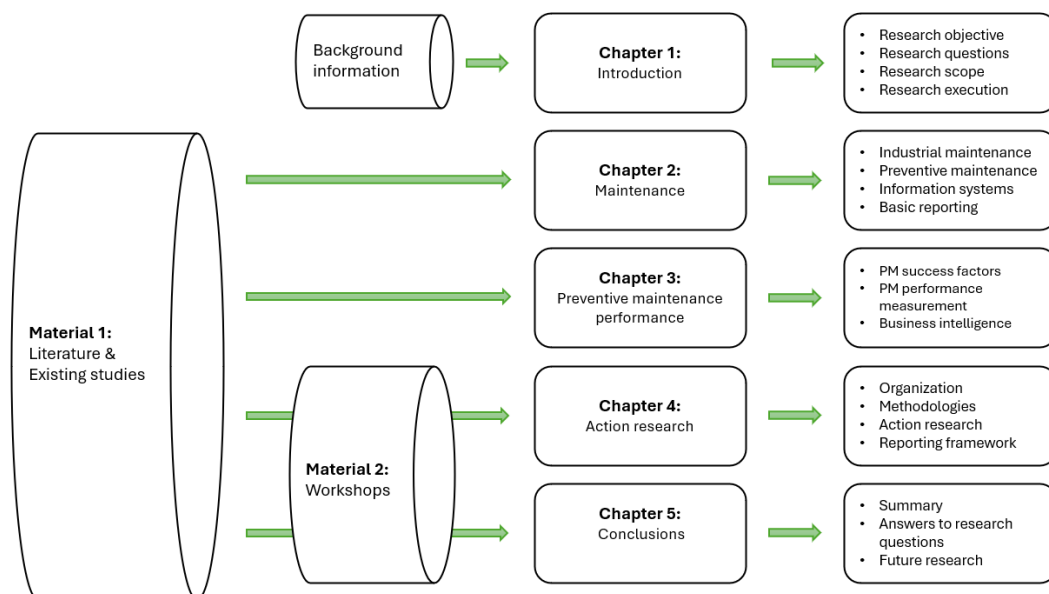


Figure 1: Input – output diagram of the research.

## 2 Maintenance

This chapter gives an overview of plant maintenance attaching it to the large-scale industry as an operating environment and deep dives into preventive maintenance in more detail. Chapter's purpose is to give the reader an understanding of maintenance in general, describe different maintenance types and maintenance importance when operating in industrial environment. In addition, maintenance information systems and their basic reporting are dealt in brief.

### 2.1 Industrial plant

An industrial plant is a facility or complex designed to carry out the production process as whole. The effectiveness of the production is typically measured by the rate of output, which reflects the efficiency of the manufacturing process in terms of the quantity and quality of goods produced within a given time frame (e.g. tons of pulp per day). Figure 2 provides a basic understanding of how industrial plant is generally structured from the highest level into the smallest components. (Kelly 2006, 55)

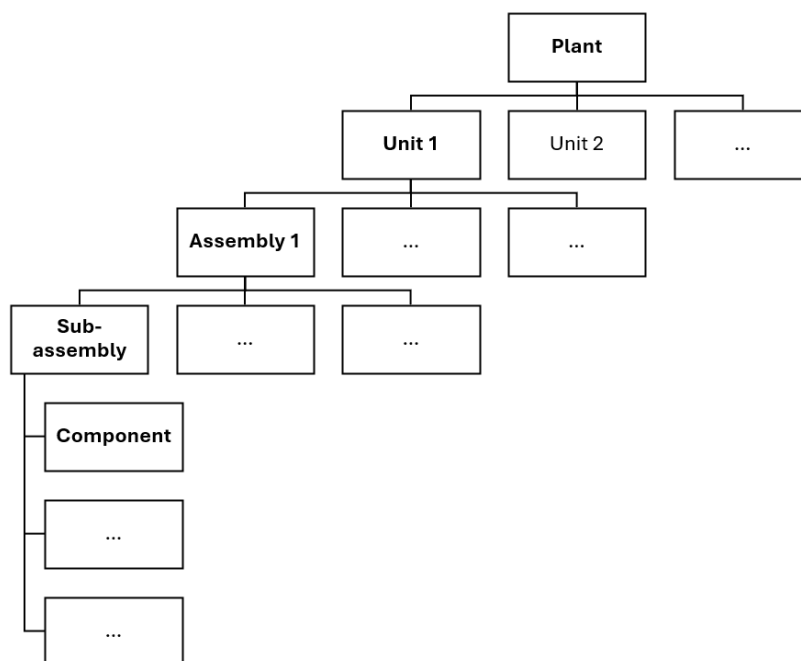


Figure 2: An industrial plant modelled as a hierarchy of parts (Kelly 2006, 55).

Plant is a highest level representing the entire industrial plant, encompassing all different units below it. The units represent a major production functions of the plant which can be replaced as a whole. Kelly (2006, 55) mentions a batch chemical reactor as an example of unit. The unit consists of assemblies, which are groups of sub-assemblies and components that are mechanically and/or electrically interconnected to carry out a major unit function. Sub-assemblies are comprised of components performing a specific function and designed to be replaced as a whole, such as a gear or a motor. The components at the lowest level are the smallest replaceable parts of the plant, for example a gear, a shaft or a bearing.

Typically, a production function is a chain of different units and machines working as a process flow. Figure 3 provides a basic understanding of a generic production process flow and why each unit and machine in the process is important and must function flawlessly. A breakdown of a one item can interrupt and stop the whole process and cause a production loss.

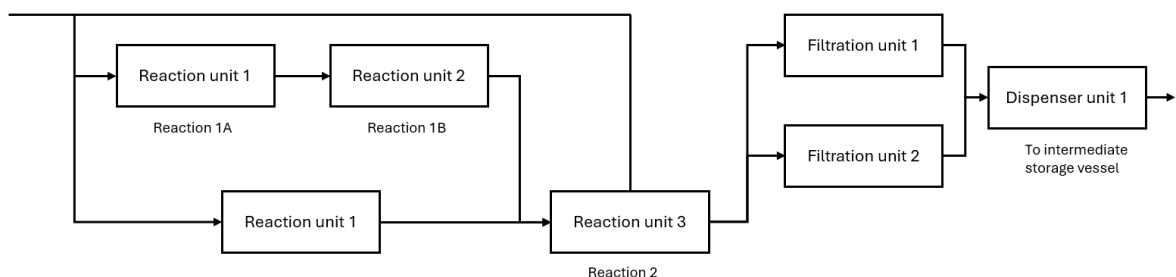


Figure 3: Generic process flow of a production plant (Kelly 2006, 59).

In this context and study, an item refers to a distinct and identifiable part, component, device, subsystem, functional unit or equipment which can be individually described and analysed on its own (SFS-EN 15341 2019:en, 6).

## 2.2 Maintenance fundamentals

In the literature and official industry standards, maintenance has been defined in slightly different ways in terms of used terminology and definitions. However, the basic principles are the same across the literature and the standards. The European Standard EN 13306 (2017:en) is used as the basis for this study. The purpose of the SFS-EN 13306 is to define

the set of universal terms applicable for all types of maintenance and its management regardless of the type of maintenance item being considered.

In SFS-EN 13306 (2017:en, 6), maintenance has been defined as following:

“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 which it can perform the required function.”

It is important to emphasize that the role of maintenance is not only to “fix the breakdown” as fast as possible. Its primary objective is to prevent all losses resulting from equipment or system-related problems (Mobley 2002, 43; Järviö & Lehtiö 2012, 15). Mobley 2004 (6-7) states that in the world-class organization, the fundamental mission of maintenance is to attain and sustain the following objectives:

- Optimum availability
- Optimum operating conditions
- Maximum utilization of maintenance resources
- Optimum equipment life
- Minimum spares inventory
- Ability to react quickly

The task of maintenance is to ensure that an item performs optimally and efficiently, with minimum cost. Maintenance costs are not limited to just direct costs of labour, materials and instrumentation. In addition to direct costs, there are also indirect costs involved in maintenance, such as work planning and scheduling, conveyance and loss of production due to downtime. To minimize the maintenance costs, it is crucial to establish and maintain a cost-efficient maintenance plan. Success of maintenance plan depends on multiple factors which are all about knowing your environment and machinery: modelling of fatigue loading, a comprehensive understanding of the mechanisms behind fatigue deterioration, the selection of appropriate inspection and repair methods, evaluation of the inspection quality, and decided inspection and repair schedules. (Zou et al. 2019, 1–2)

Maintenance is divided into different types. SFS-EN 13306 (2017:en, 31) divides the maintenance based on a fault. Maintenance types by this standard are presented in the figure 4. A fault is defined as following:

“State of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources.”

All actions before a fault of an item belong to preventive maintenance. Correspondingly, corrective maintenance is defined as the actions after a fault.

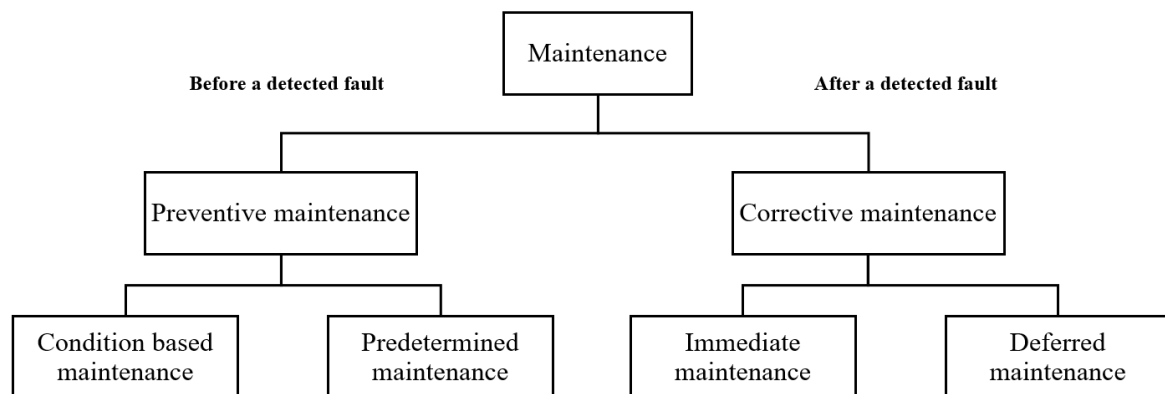


Figure 4: Maintenance types (SFS-EN 13306 2017:en, 58).

Corrective maintenance is carried out after a detected fault. Objective is to restore an item so that it can perform a required function again. (SFS-EN 13306:2017:en, 38) As a maintenance strategy, corrective maintenance is an original one and it has been in use for a long time in industry (Waeyenbergh & Pintelon 2002, 301). However nowadays, the task of corrective maintenance is to act fast when an item has failed, and production has stopped despite of preventive maintenance actions. Corrective maintenance is essential component of maintaining efficient and productive production, as it is not feasible or economically viable to aim for zero equipment failures in a normal production facility. (Quintana et al. 2009, 3540)

Corrective maintenance is divided into two subtypes: immediate and deferred. Immediate corrective maintenance is carried out without delay after the fault detection to avoid unwanted consequences and minimize the production losses. On the other hand, deferred

corrective maintenance is not carried out immediately after the fault detection and is delayed according to situation. (SFS-EN 13306:2017:en, 38)

Preventive maintenance will be discussed next in more detail as it is in the focus of this study.

### 2.3 Preventive maintenance

Preventive maintenance is characterized as a type of maintenance that is performed with the intention of evaluating and/or mitigating degradation, to minimize the possibility of an item's failure (SFS-EN 13306:2017:en, 34). Preventive maintenance is important in order to reduce probability of failures with purpose to optimize overall costs (Syamsundar et al. 2021, 1). Preventive maintenance, which falls under the category of planned maintenance, is significantly more cost-effective than corrective maintenance, which falls under the category of unplanned maintenance. This is often highlighted by stating that planned maintenance is 4-10 times more efficient than unplanned maintenance. (Järviö & Lehtiö 2012, 103)

As presented in the figure 4, preventive maintenance is divided into predetermined maintenance and condition-based maintenance. The predetermined maintenance is a type of maintenance that is performed according to defined intervals of time or a specific number of units of usage without prior condition investigation. This means that maintenance is performed according to predetermined schedule without considering the actual condition of the item. Good examples of predetermined maintenance are lubrication, oil changing and cleaning. (SFS-EN 13306:2017:en, 35) Preventive maintenance is all about knowing your equipment and their maintenance needs. It is possible by following an item's performance and/or its parameters. Based on the results, preventive maintenance actions can be planned and scheduled. (Järviö & Lehtiö 2012, 50) The good thing of predetermined maintenance is its regularity: it is always known beforehand compared to condition-based maintenance (Syamsundar et al. 2021, 2).

Condition-based maintenance is a type of maintenance which includes evaluating the physical condition of an item, analyzing the results and performing the necessary maintenance actions. Condition evaluation can be performed through operator observation, inspection, testing or continuous condition monitoring of system parameters. Condition-

based maintenance can be conducted based on a schedule, upon request or continuously. (SFS-EN 13306:2017:en, 35) When condition-based maintenance is implemented effectively, it provides the advantages of preventive maintenance while also creating a chance to minimize the costs associated with unnecessary excessive scheduled maintenance and keeping the operational health of the equipment. (Gruber et al., 2020, 207)

Bathtub curve presented in the figure 5 illustrates the failure rate variation of an item during its lifetime. The lifecycle is commonly divided into three phases. Failure rate is high in the beginning of the item's lifecycle, because of the planning mistakes and manufacturing defects. Failure rate decreases when these defects are corrected. (Ohring & Kasprzak 2015, 32) Second phase is so called "useful life", and there the failure rate is more less stable and happen at random. In this phase, preventive maintenance is in a key role. By implementing the appropriate preventive maintenance strategy for the critical items of the system, the bathtub's constant level can be lowered. (Sørensen & Sørensen 2011, 206) The last part of the bathtub curve is called a wear-out phase where the failure rate increases due to the acceleration of wear-out mechanisms. (Smith 2022, 22)

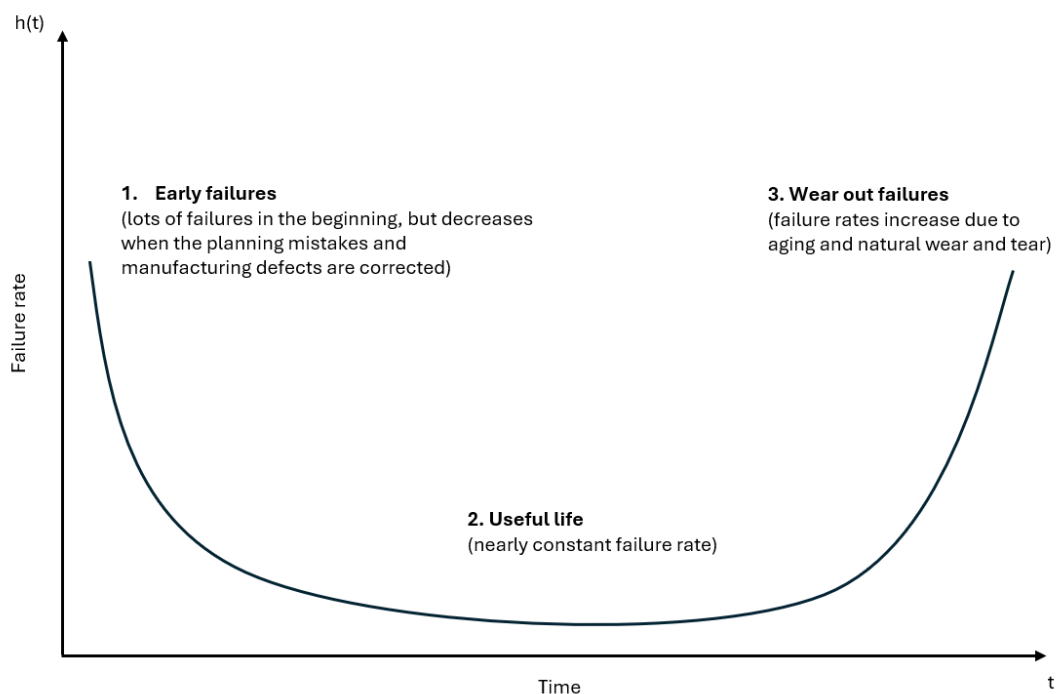


Figure 5: Bathtub curve (Smith 2022, 23).

## 2.4 Maintenance information systems

Companies control their different functions and information with enterprise resource planning (ERP) and reporting systems. By using these systems, companies aim for integration and automatization of the information. (Järviö & Lehtiö 2012, 265) In the maintenance context, there are generally used terms for a system as such: maintenance management system, EAM (Enterprise Asset Management System) and CMMS (Computerized Maintenance Management System). In the maintenance management context, ERP system serves the maintenance management and material management which has the required connections to other information systems of the production plant. (Mikkonen et al. 2009, 116)

Maintenance information systems generally have the similar basic functionalities. Manzini et al. (2010, 190) summarize the maintenance information system's role and functionalities in the figure 6. Maintenance information system must support all maintenance activities including 1. data collection, 2. maintenance engineering, 3. interventions and workload analysis and 4. spare parts and equipment management. Each of these sections are divided further into subareas. Although these strongly interconnected areas have different objectives, they must collaborate harmoniously to achieve the company's maximum economic results.

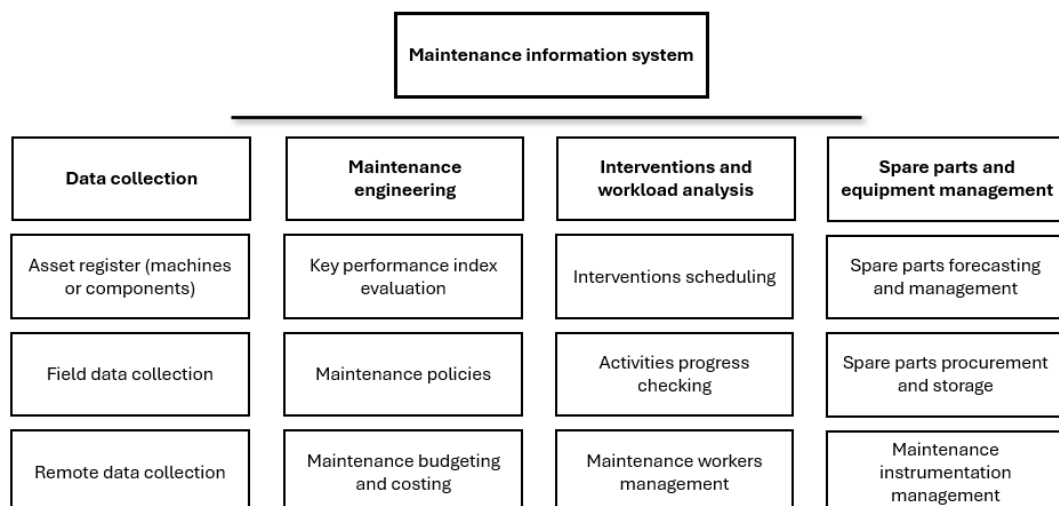


Figure 6: The role of maintenance information system (Manzini et al. 2010, 190).

Data collection is a fundamental for the maintenance management. It means that all the relevant information is gathered into the system. (Mikkonen et al. 2009, 121) Data collection

consists of defining the plant characteristics such as how it is structured including the functional locations, equipment and work centers. This also includes the definition of criticality of the components. Setting up this kind of master data constructs the asset register (equipment and/or components), and it can be described as “static information”. Asset register is the core of the entire maintenance management system (Mikkonen et al. 2009, 117). Once the so-called master data is setup, data must be gathered from the field. It is generally handled by two types of documents which construct the maintenance workflow: failure notifications and work orders. By utilizing notifications, plant personnel notify and register the failures in the plant, and describe all the relevant information such as location, equipment, failure mode, failure cause and effects. Work orders are meant to describe the actions and requisites needed to complete the work such as job description, work duration, resources and required spare parts. These two document types continuously collect the maintenance history data into the database. In addition, data can be also collected remotely and automatically from the connected systems. (Manzini et al. 2010, 191–193)

Maintenance engineering is the area, which focuses on the analysis and optimization of maintenance processes. Specifically, it means evaluation of key performance indicators and determination of the most effective maintenance policies. (Manzini et al. 2010, 194) This section also offers the tools for maintenance budgeting and costing. It means gathering all the maintenance generated costs into the system which enables the cost control. Objective of this subsection is to monitor the maintenance cost and performance from economic point of view. (Mikkonen et al. 2009, 118)

A successful maintenance system requires the coordination of various policies. It is often challenging to manage due to large number of machines involved, the significant impact on production losses and the large number of workers engaged. Here, interventions and workload analysis come as an important factor. Planning and scheduling of the interventions (also called as shutdowns) and preventive maintenance actions has a significant impact on the productivity of the plant. (Manzini et al. 2010, 195) With an effective planning and implementation, company can increase the annual production even by few percentages (Laine 2010, 163). Kister and Hawkins (2006, 58) broadens the importance of planning and scheduling to all maintenance activities. Without efficient maintenance planning and scheduling, it is impossible to manage the diverse range of maintenance activities performed by the maintenance organization. Planned maintenance is in a key role in minimizing the

waste time and delays that personnel face while carrying out unplanned work. In this manner, maintenance information system has a significant role.

Maintenance cannot be carried out without a proper spare part and equipment management. Maintenance information system keeps track of plant's warehouses and spare parts in there. It also includes the information of the equipment's spare parts. (Mikkonen et al 2009, 118) This section also includes the consumption information of the spare parts needed in the history. To maintain the required spare parts in the warehouses for the smooth maintenance, the system has a procurement function. (Manzini et al. 2010, 195–196) Equipment management tracks the basic information such as equipment characteristics, its history and preventive maintenance schedule (Duffuaa & Raouf 2015, 225).

Manzini et al. (2010, 190) present the maintenance information system in broad way in the figure 6. As a comparison, Mikkonen et al (2009, 116) present the maintenance information system's functionalities in slightly different fashion by clarifying and highlighting the concrete functions of the system and their interconnection in the figure 7. It also highlights that the maintenance information systems can be customized and expanded in many ways to many different areas based on the company's needs and examples of those additional functionalities are shown with the dotted rectangles. Many of these functionalities in the figure 7 are closely linked to the preventive maintenance, such as equipment register, work orders, maintenance history, material management and condition monitoring. Figure 7 also highlights the reporting functionalities of the maintenance information systems. As a comparison, in the figure 6, reporting can be identified as part of the maintenance engineering.

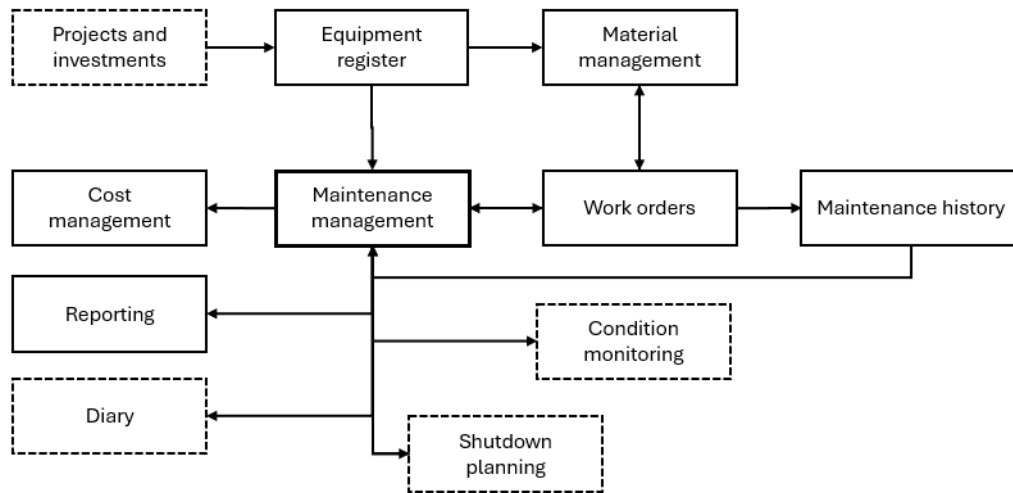


Figure 7: Simplified figure of maintenance management system's general functions and features (Mikkonen et al. 2009, 116).

ERP system has a significant or even necessary role in the maintenance management (Kłos & Patalas-Maliszewska 2013, 15–16). In addition to the system itself, development of cost-effective maintenance requires utilization of data analytics and systematic processes. These enable the effective utilization of the system and development of the maintenance actions based on the data analysis. (Laine 2010, 39)

ERP must be implemented and used properly so that it can support decision-making efficiently and reliably. Efficient maintenance operations rely heavily on the seamless flow of information. It is essential to register all the events of the equipment including all the notifications, breakdowns, inspections, repairs and so on. ERP system supports the organization keep record of all these events. It enables the data collection of the maintenance operations for the performance measurement and business intelligence solutions. (Kłos & Patalas-Maliszewska 2013, 15–16)

## 2.5 Basic reporting in maintenance

As stated in the previous chapter, maintenance systems generally have their own out-of-the-box reporting capabilities. This reporting module of the maintenance information system gathers the information of the functions and enables to follow-up and control the maintenance activities. This is provided by the various kinds of performance and cost

reports. The reports can be often customized in many ways. (Duffuaa & Raouf 2015, 235) The reports offer analysis and investigation possibilities of the operations for example based on equipment, department or time period (Väänänen et al. 2003, 43) and has various kind of filtering possibilities (Järviö & Lehtiö 2012, 119).

Duffuaa and Raouf (2015, 235) list some examples of the commonly provided reports by the maintenance information system:

- Cost reports offering the details about maintenance costs by different dimensions such as locations, equipment and cost centers
- Completed work orders illustrating the work completed in a specified time range
- Backlog report of the work orders waiting for actions
- Work order status report illustrating the work progress in different stages
- Maintenance work distribution by priorities
- Estimated and actual work hours comparison report

However, often the usability and practicality of these out-of-the-box reports comes as an issue. This is caused by the dozens of reports which users need to go through the get the information they are looking for. (Väänänen et al. 2003, 43) In addition, usually these systems are not supporting significant features, for instance failure reports (Simoes 2011, 125).

As maintenance information systems offer a basic reporting for querying and analyzing the data, chapter 3.3 delves into the utilization of business intelligence as a tool to enhance performance reporting to be more practical and user-friendly.

### 3 Preventive maintenance performance

This chapter focuses on the preventive maintenance performance, its measurement and the role of business intelligence in the context.

#### 3.1 Preventive maintenance performance measurement

Company's existing historical data and policy knowledge enables maintenance management to utilize data in the decision-making process to improve effectiveness. To improve maintenance effectiveness, it is essential to measure it. Performance indicators are measuring the maintenance process. (Sigsgaard et al. 2021, 1–3) Same applies to preventive maintenance improvement. Following phrase that is often related to famous management consultant and writer Peter Drucker, describes well the importance of performance measurement: "If you can't measure it, you can't improve it."

Performance indicators are used to pinpoint deficiencies in a company. However, it is important to understand that indicators alone act only as pointers. To reach a resolution, additional analysis is a necessity. Therefore, in addition to performance indicators, there should be multi-level indicators and supportive information to be able to find the problem and create a solution. (Parida et al. 2015, 6) As this study focusses on the maintenance performance measurement, it is natural to refer as maintenance performance indicators (MPIs).

As a first step in the performance measurement, it is essential to understand organization's operating environment and needs, and thereafter develop the maintenance measurement system. This means identifying the success factors. Second, measurement system is always meant and developed for the personnel so the importance of training cannot be forgotten. Third, performance measurement requires quality data and its analysis. Fourth, it is crucial to have management involved in the whole process and have strong commitment and support from top management. (Parida & Kumar 2006, 243–244)

According to Parida and Kumar (2006, 243), when designing and developing a maintenance performance measurement framework, the following factors should be considered by addressing them with the following questions:

- What are the most relevant indicators for business and related to maintenance?
- How do the indicators relate to each other and answer the requirements of stakeholders?
- Can MPis be objectively measured?
- How do the MPis assess the efficiency of the organisation?
- Are the MPis at the same time appropriately challenging and still achievable?
- Are the MPis linked to quantitative or qualitative benchmarks or milestones?
- How do the MPis guide the actions or how are the decisions made based on the MPis?
- What corrective and preventive measures are in place and when and how MPis should be updated?

A widely accepted way to evaluate the quality of the key performance indicators (KPIs) is so called SMART criteria. It stands for S as specificity, M as measurability, A as achievability, R as relevancy and T as timely. (Selvik et al. 2020, 1000) Meaning of these criterions are presented in the table 1.

Table 1: SMART criteria for KPI quality evaluation (Selvik et al. 2020, 1000).

<b>Criterion</b>	<b>Description</b>
Specificity	KPI must be clear, unambiguous and consistent for the precision
Measurability	KPI must be comparable and quantifiable with high-quality data
Achievability	KPI must be realistic and guide to target attainment
Relevancy	KPI must be essential for business management and improvement
Timely	KPI must cover appropriate timeframe for comprehensive insights

Once the appropriate performance indicators have been chosen, they must be presented visually in effective way to create knowledge about the data. It is also crucial to use straightforward and simple visualizations because there will be many numbers that need to

be communicated simultaneously through the visualizations. (Sigsgaard et al. 2021, 3) It is also important to scope and limit the number of used performance indicators as low as possible as a long list of indicators becomes an exhaustive and impossible to monitor and control (Parida et al. 2015, 13). Neely and Bourne (2000, 6) states it wisely and concisely: “The trick is to measure as little as possible, but to ensure that you are measuring the things that matter.”

### 3.2 Preventive maintenance success factors

Simplified, in the context of preventive maintenance, two success factors can be identified: planning and scheduling. As a third one, schedule compliance can be identified. (Järviö & Lehtiö 2012, 100–109) Planning the preventive maintenance program is a first step. When the preventive maintenance program has been established and validated, preventive maintenance compliance can be measured. (Idhammar 2013, 10) Typical problems in preventive maintenance programs are that they are either too narrow or unnecessarily extensive. Both cases lead to increased amount of corrective maintenance, as important preventive maintenance actions are either missing or drowning into the mass of actions. (Caverion 2021) This study does not focus into actual preventive maintenance planning in detail level but focus on creating a visibility of what kind of preventive maintenance tasks have been defined, for which items and how.

Preventive maintenance planning is one of the most difficult areas in the maintenance. Defining an efficient preventive maintenance program requires extensive understanding of the items and their characteristics, criticality, failure modes and effects. (Järviö & Lehtiö 2012, 100) However, quite often the preventive maintenance plans are defined based on the manufacturer’s instructions which have been bit adjusted by the industrial plants’ previous experience of item failures (Laine 2010, 124). Järviö and Lehtiö (2012, 100) adds the spare parts and their consumption, machine and its items functioning method to the information which is used to define the preventive maintenance plans.

There are two often utilized preventive maintenance planning approaches: criticality analysis and reliability centered maintenance analysis (RCM). These methods are also often combined when conducting preventive maintenance planning. (Mikkonen et al. 2009, 146) Criticality analysis means functional locations and equipment categorization based on their

criticality. Criticality classes are often A, B and C. Preventive maintenance plans are focused especially on the most critical, A-B classified, functional locations and equipment. On the other hand, RCM based preventive maintenance planning is conducted based on analysis of process functions and their failures impact including losses and cost. (Järviö & Lehtiö 2012, 100)

When creating and targeting a preventive maintenance plan, following things should be considered according to Laine (2010, 130):

1. Dividing equipment into components
2. Evaluation of equipment failure methods
3. Selection of maintenance actions
  - a. Inspections
  - b. Periodic servicing
  - c. Cleaning
4. Reliability evaluation
5. Maintenance actions scheduling for the year
  - a. Bundling and scheduling of actions
6. Maintenance work instructions
7. Documentation
8. Evaluation

Literature and industry standards introduce various KPIs to measure and control the preventive maintenance performance. In the preventive maintenance planning, one of the first tasks and a pre-requisite is criticality classification of items. There, one essential measure is a criticality of items: total number of critical items and total items installed. (SFS-EN 15341:2019:en, 31) In order to create efficient and cost-effective preventive maintenance plans, we need to know what our critical assets are and what are less critical assets.

Preventive maintenance execution efficiency can be measured with the KPIs such as preventive maintenance compliance and percentage of preventive maintenance (Ku & Kim

2018, 75). Preventive maintenance compliance measures how accurately maintenance teams are completing the defined maintenance plans: overall and on the schedule (Lundgren et al. 2020, 1297). Percentage of preventive maintenance can be measured by dividing preventive maintenance hours or cost by total maintenance hours or cost (SFS-EN 15341:2019:en, 36–41). Other introduced measures for measuring preventive maintenance are mean time between failure (MTBF), preventive maintenance cost per equipment, non-quality production volume and production loss (Laine 2010, 242). There are hundreds of different measures to be applied but finally, KPI selection should be guided by the company's vision and strategic goals (Lundgren et al. 2020, 1291).

### 3.3 Role of business intelligence

Business intelligence can be described as a process of generating relevant and accurate information to the right people at the right time. The term includes all the skills and resources that are required to transform raw data into understandable information that everyone in the organization can trust and use for the effective decision-making. Business intelligence is in key role when companies are seeking competitive advantage. (Miller et al. 2006, 3) In recent times, IT-based performance measurement systems have increased. The spread of business intelligence has had a profound impact on performance measurement within organizations. Business intelligence enables the performance measurement through its ability to gather, analyze and present the data. Data can be presented as information in many formats of reporting such as automatized reports, dashboards and platforms. Business intelligence can be used to measure performance. (Vallurupalli & Bose 2017, 72) As a conclusion, business intelligence can be seen as an enabler – empowering organization to become smarter, work more efficiently and make informed decisions by utilizing the information (Larson & Chang 2016, 700).

Data visualization is in a key role in the business intelligence context. The main objective of data visualization is to communicate and present the data in understandable and effective way. (Few 2006) Data visualization aims to simplify and communicate the complex data through visual and graphical representations, enabling the decision-makers to easily understand and make decisions in complex and difficult concepts and ideas. Basically, it aims the same as “a picture is worth a thousand words”. (Lea et al. 2017, 923) As it was

stated in the chapter 2.5, challenge of maintenance information systems' out-of-the-box reporting is the large number of reports causing the complexity of use and difficulty to understand. Here, business intelligence comes as a powerful tool.

In addition to its great capability to visualize information, business intelligence tools enable the analysis of the data. This means that data can be analyzed easily from different perspectives by slicing and dicing. Another aspect is the drilling down characteristic in business intelligence tools, which enables the data presentation in hierarchical format. The most important information can be shown in simple and easy way of presentation and drilling down enables to investigate the details and deficiencies. (Burstein & Holsapple 2008, 180–181)

Even though this study is not touching advanced analytics and is focusing on the traditional business intelligence in the form of reporting to measure performance, it is essential to cover data utilization levels briefly. These levels set the future targets in climbing up the ladders. Data analytics is a close term with the business intelligence. Data analytics can be defined as the utilization of computer systems to analyze large data sets to support the decision-making (Runkler 2016, 3). In the figure 8, we can see the levels of data utilization. In the higher level in the pyramid, more advanced analytics is required. At the same time, the value of the information achieved by data analytics to businesses grows and the understanding of analytics users enhances. (Martinsuo & Kärri 2017, 126)

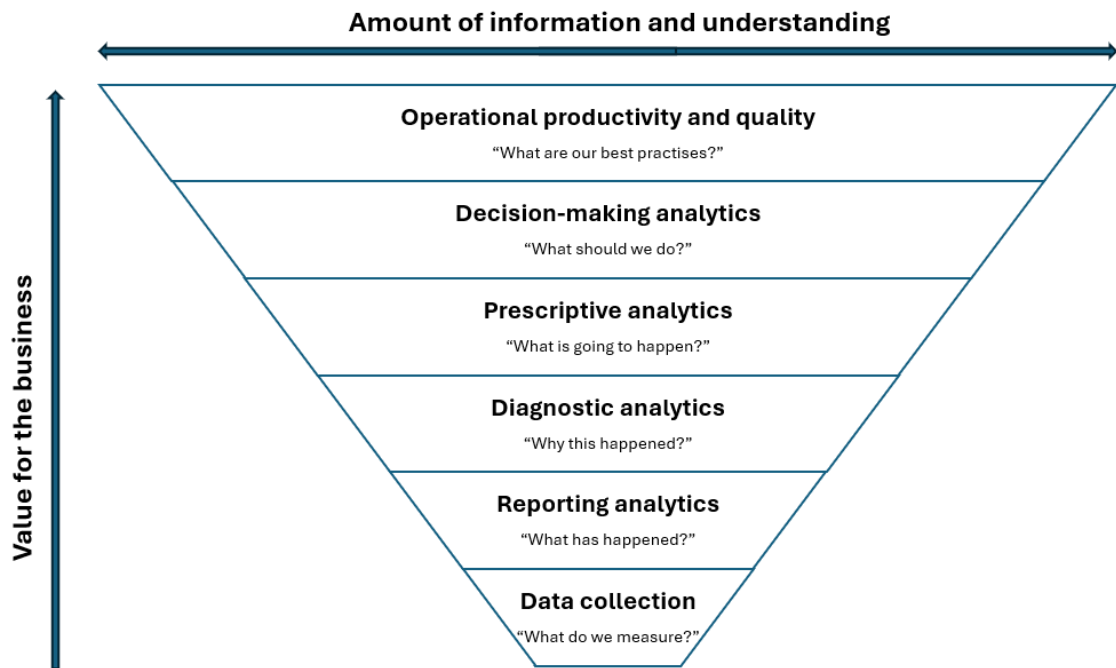


Figure 8: Compiled information enables informed decision-making (Martinsuo & Kärri 2017, 126).

To start practical development of the maintenance performance measurement system for an organization, data of the operations must be available. Data analytics and business intelligence are tools to practically implement the maintenance performance system.

## 4 Action research: development of preventive maintenance reporting framework

This chapter offers a brief description of the research company and its operating environment, including a thorough examination of the company's specific needs and challenges that motivated this action research. It provides a detailed overview of the methodologies employed, highlighting the steps taken to implement the action research. Finally, the chapter presents the preventive maintenance reporting framework.

### 4.1 Organization and needs

The research was completed in a global renewable materials company. Company operates around the world having dozens of units in Europe, Asia and South America. Company consists of five divisions as the business areas. Four of the divisions are connected into this research. Company operates in capital-intensive business. It means that company requires significant investments in fixed assets such as machinery, equipment, and technology, to produce its goods or services. In capital-intensive industry where the company operates in, the costs associated with acquiring and maintaining the assets can be substantial.

Maintenance is a critical factor in ensuring the efficient and effective operation of the machinery and equipment that is used to produce goods. Failure to maintain these assets can lead to costly breakdowns, repairs, and replacements, which can significantly impact the financial performance of the company. By having a preventive maintenance strategy and improving the related actions, company can reduce the risk of unplanned downtime, increase the lifespan of its assets, and improve overall productivity. This can involve regular inspections, preventive maintenance, and ongoing monitoring to identify and address potential issues before they become major problems. By prioritizing maintenance as a key factor in its operations, company can minimize the risk of costly disruptions, ultimately contributing to its long-term success and sustainability. All the information is in the company's maintenance management system, but its out-of-the-box reporting is providing only the basic information mainly in tabular format and comprehensive overview cannot be easy achieved.

Here, comprehensive and successful preventive maintenance reporting solution can help company in several ways. Company's current maintenance reporting solution's problems are the complexity and exhaustive number of report pages, measures and visualizations. This was stated in the preliminary study of the current reporting solution which gathered valuable inputs from the organizations' business and technical personnel regarding the challenges and improvement areas of the current solution. Preliminary study findings are well in line with the literature review highlighting the importance of compact and insightful reporting solution with meaningful, consistent and quality data. Objective of this study is to tackle these problems and design a compact and dedicated preventive maintenance reporting solution that gives an overview of the most important preventive maintenance success factors. In addition, the reporting solution works as a tool to manage and enhance preventive maintenance performance in the company's industrial plants around the world. As per the preliminary study, the main target user groups of the reporting are maintenance management, maintenance engineers and planners.

Regardless of the company's industrial plants being different from each other and operating in different business areas, there are a lot of common in plant maintenance operations. By knowing this, it is important to seek similarities and collaborate widely across the organization when developing business intelligence solutions that can be utilized in the entire organization. One common reporting solution enables to follow same measures in the entire company based on the same data models and calculations. It is also relevant to note that the preventive maintenance reporting is only one part of the company's entire maintenance reporting solution.

As described in the chapter 2.4, maintenance information system is in a key role in the maintenance management. It allows the data collection of maintenance operations data, which can be utilized for performance measurement and business intelligence solutions, such as preventive maintenance reporting solution. Company uses SAP as its ERP system. SAP has extensive functionalities and all functions in one system. SAP Plant Maintenance module is focused on the maintenance and used to manage several functions, such as:

- Equipment management
- Maintenance planning
- Spare part management

- Maintenance personnel management
- Maintenance cost management

## 4.2 Methodologies

To develop the preventive maintenance reporting framework that caters to all maintenance reporting users across the company, it is essential to conduct the research in collaboration with end-users of the reporting. In addition, the four participating divisions of the company represent different business areas, and their needs slightly differ. This must be considered in the research. Considering the research environment, research questions and characteristics of the development need in a company, action research was chosen to be the most appropriate research methodology. Action research is all about people interacting together and learning in the process to be able to take purposeful action to improve a thing (McNiff 2013, 25).

### **Action research**

Action research is considered as a qualitative research (Kananen 2014, 20). It originated in the United States in the 1940s when Kurt Lewin invented a term ‘action research’. Action research does not have commonly known and agreed definition; it is rather about the way of approaching the research object, instead of specific and strictly defined research method (Cohen & Manion 1980, 174). Carr and Kemmis (1986, 152) names two main objectives for the action research: development of operations and influencing a problematic operational situation.

Action research starts from a recognized problem or area for development within an organization, which the management seeks external assistance, such as research insights, to resolve (Sein et al. 2011, 40; Davison et al. 2004, 73). Action research applies to any research involving performers and “customers” – individuals seeking results. It is applicable where agreement can be researched in activities or at least where there is no conflict in goals or underlying valuations. (Anttila 1996)

Below figure 9 illustrates the action research process, which encompasses a series of interconnected cycles, so called ‘spiral of cycles’. A cycle consists of different activities starting with identifying an initial idea, finding the facts and analysis, general planning,

implementation of first action step, evaluation and revising general plan. Thereafter, researcher spirals to the next cycle. (Elliott 1991, 69)

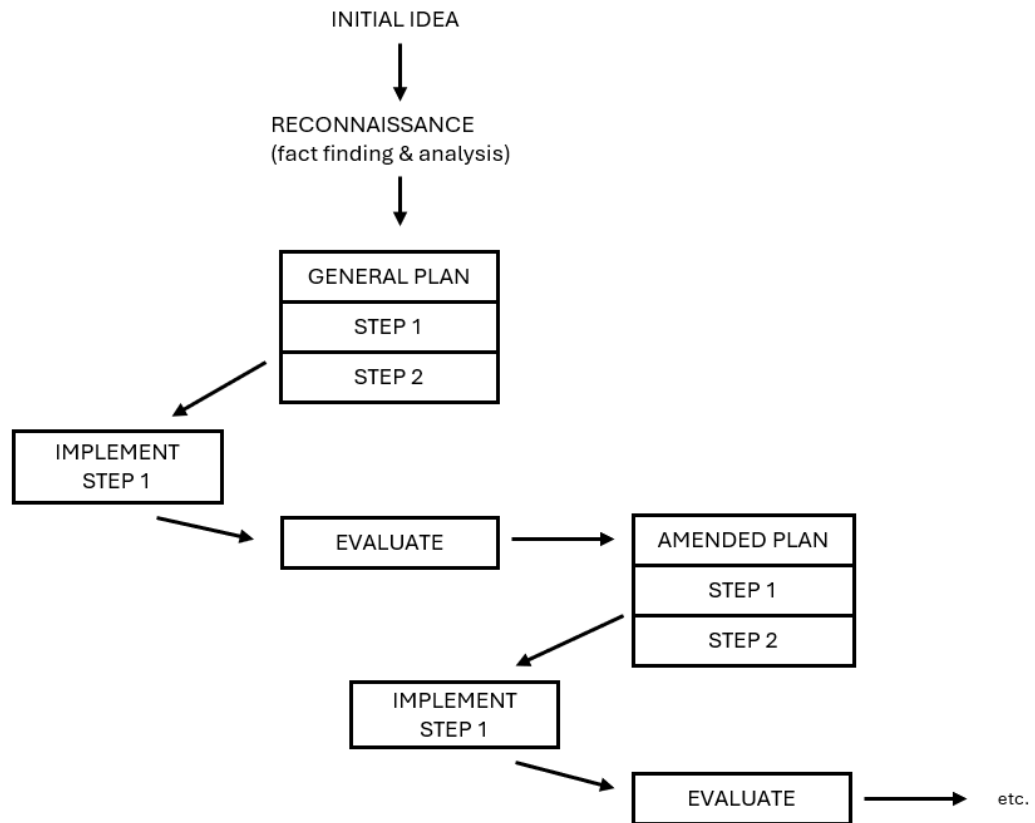


Figure 9: Kemmis's interpretation of Kurt Lewin's model of action research (Elliott 1991, 70).

### Workshops

In the research company, the main problem and needs had been recognized and it generated the need for this study. However, developing a new preventive maintenance reporting solution requires an intensive discussion and ideation with the organization to design a new solution that serves the needs of the company. In this context, workshop as a methodology was chosen to be utilized as a powerful tool to gather needs and insights and create new together.

Workshop is an arranged and structured gathering where group of people engage to creatively solve the problems, generate innovative solutions, learn and expand their

knowledge in relationship to a domain-specific matter. Workshops in research seek to generate reliable and accurate data regarding forward-thinking processes, such as organizational change and design, within the specific domain in question. (Ørngreen & Levinsen 2017, 71–73)

In a workshop, there is a facilitator and participants. Facilitator is an experienced individual who is familiar with the domain in question (Ørngreen & Levinsen 2017, 72). Facilitator leads the workshop and by the instructions and actions supports participants to interact and collaborate in finding solutions into the domain. Facilitator must create an open environment to the workshop where all participants feel themselves comfortable and important. Recommended ways to provoke participants to speak their minds is to use questions prompts, cues and activities. (Ahmed & Mohd Asraf 2018, 1504–1510) In the research context, researcher acts as the facilitator (Ørngreen & Levinsen 2017, 73).

The participant group is intentionally limited as small to ensure participants' personal attention and enable every individual to feel their voice is heard. It is expected that participants actively participate into discussion and influence the workshop direction. Finally, workshop facilitator and participants expect and aim to find an outcome, for example to generate new insights and innovations, design or re-design a product and processes. (Ørngreen & Levinsen 2017, 72)

In the research context, workshops must be purposefully designed to achieve a research purpose: produce reliable and valid data. Here, documentation of the workshops comes crucial. Darsø (2001, 220) divides data to primary and secondary: primary as generated real-time and secondary as retrospective descriptions based on all types of records: what happened. As primary data is generated in real-time in the workshops, Darsø (2001, 220) proposes documenting primary data through extensive personal notes, mind-maps and symbols, video recordings, artifacts and presentations created during the workshop. In this research, primary focus is collecting the primary data because it is seen to serve best the research context.

### **Design thinking**

When it comes to the development a new solution, design thinking is a powerful method. It is a way of working which is rooted in a design process (Dekker 2020, 49). Design thinking has a strong focus on problem-solving (Clarke 2020, 10). In its essence, design thinking's

problem-solving approach leans on creativity, collaboration and systematic problem identification and resolution (Luchs et al. 2016, 21).

In the literature, authors have named the phases of the design process in a slightly different way, but they all follow the same ideology and frame. Luchs et al. (2016, 24) define it as shown in the figure 10. Clarke (2020, 14) define it similarly, but adds idea generation phase between the definition and creation. Dekker (2020, 55) use four phases as discovery phase, definition phase, development phase and implementation phase.

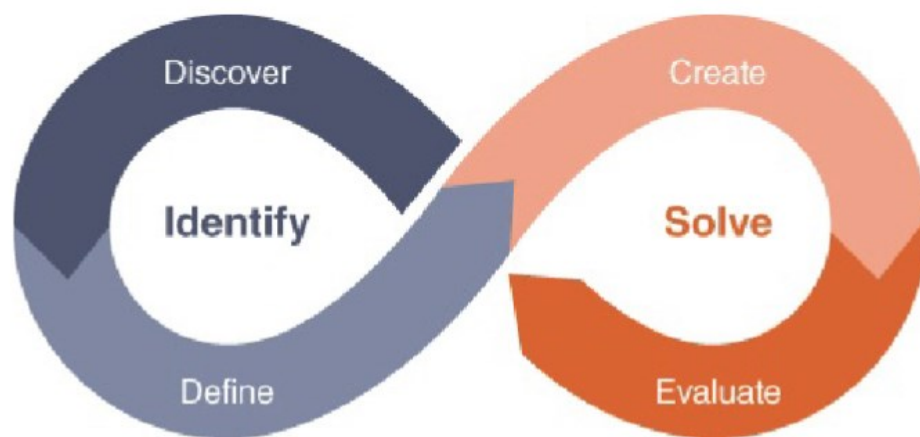


Figure 10: A design thinking process (Luchs et al. 2016, 24).

The process starts with the discovery which is for inspiration and generating insights. In this phase, the objective is to gather the initial needs of the users, draw the frames and generate the initial ideas about the problem. (Dekker 2020, 56) In the discovery phase, the researcher focuses on gaining the comprehensive understanding of the users. In this phase, emphatic attitude and comprehension is in a key role. (Clarke 2020, 14)

In the definition phase, gathered insights and ideas in the discovery phase are defined and prioritized. It continues from the ideas and insights into more details and objective is to define the exact problems that could be solved. It aims to frame the insights into a concrete problem statements or questions. (Luchs et al. 2016, 25)

The creation phase focuses on developing the prototypes and concepts. The creation phase includes the ideation and prototyping. (Luchs et al. 2016, 27) By creating the prototypes or so-called low-fidelity preliminary mock-ups, ideas can be tested and feedback gathered.

These prototypes of mock-ups are meant to be quick first versions – not shiny and finetuned end results. (Clarke 2020, 15)

The evaluation phase is centered on gathering the feedback on the prototypes and mock-ups. In this phase, it is important to get ideas, and improvement needs from the team so that the mock-ups can be iterated and improved. (Luchs et al. 2016, 27) This evaluation phase through the gathered feedback exposes the improvement needs and new problems to be tackled. From here, the cycle of design thinking starts again. (Clarke 2020, 15)

In the figure 11, the design thinking process is illustrated. It also highlights that a design thinking process consists of multiple cycles of design thinking and through that underlines the iterative process.

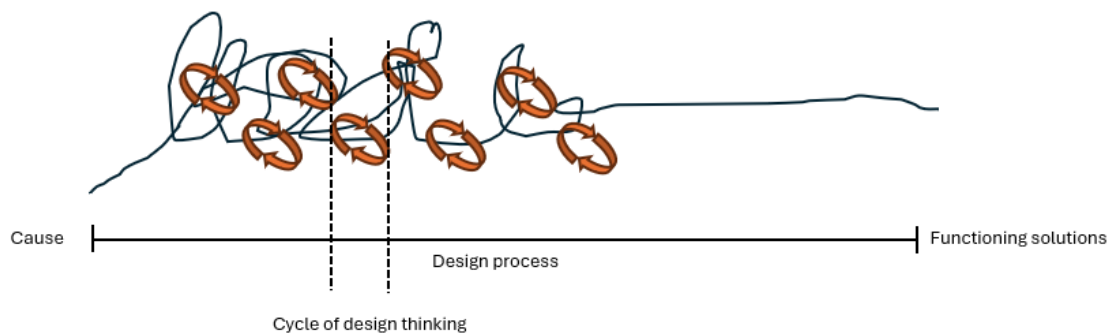


Figure 11: The design process and cycle of design thinking (Dekker 2020, 49).

### 4.3 Workshop implementation

Workshop planning began by mapping suitable participants who are experienced specialists in the preventive maintenance domain and maintenance in general. Based on the literature review findings and suggestions, aim was to establish a small participant group to intensively collaborate in the workshops within the domain and innovate the solution. This approach was supported by the fact that framework creation did not require wide range of different ideas, but rather creating a focus and finding the most important things to include in the reporting framework. In the research company's environment, it was also crucial to consider country and divisional characteristics and involvement of different perspectives when forming the participant group. Considering the literature suggestion of having small

workshop participant group, but also the research environment and a need to gather requirements and involve people from company's many operating countries and divisions, conclusion was to establish a core group who would form the workshop participant group. In addition, a broader reference group of people was established to provide additional insights to the topic and feedback to the preliminary framework created by the core group. Purpose of the reference group was to supplement the core group's insights and ensure the final reporting framework represents the vision of the wider group.

As presented in the table 2, the core group was limited to two experienced maintenance specialists from two divisions and countries. They both have extensive, over 15 years' experience in large-scale industry maintenance, have served in various roles, worked in many maintenance related development programs and have years of history in the company. The researcher acted as a facilitator working closely with the core group during the process.

Table 2: The core group representatives.

<b>Representative</b>	<b>Title / Role</b>	<b>Location</b>	<b>Experience in years</b>
Representative 1	Operations Development Manager	Country 1, Division A	+15
Representative 2	PM Workflow Manager	Country 2, Division C	+20

The reference group participants were selected together with divisional key maintenance representatives with aim to have extensive coverage of people from many countries, divisions, production plants and maintenance roles. Reference group consisted of 20 people from three countries, four divisions and six production plants. Selected reference group members were working in the several roles including maintenance engineer, maintenance manager, production manager, shutdown manager, maintenance director, technical manager, development manager and operation development manager. These people also had comprehensive experience from different maintenance roles inside and outside of the company. Reference group representatives can be seen in table 3.

Table 3: The reference group representatives.

<b>Representative</b>	<b>Title / Role</b>	<b>Location</b>	<b>Experience in years</b>
Representative 1	Operations Development Manager	Country 1, Division A	+20
Representative 2	Operations Development Manager	Country 1, Division B	+20
Representative 3	Operations Development Manager	Country 2, Division A	+20

Representative 4	Operations Development Process Manager	Country 2, Division B	+20
Representative 5	Senior Technical Manager	Country 3, Division C	+15
Representative 6	Head of Operations IT	Country 1, Division D	+15
Representative 7	Maintenance Director	Country 1, Mill C	+20
Representative 8	Maintenance Manager	Country 1, Mill A	+10
Representative 9	Maintenance Manager	Country 2, Mill B	+15
Representative 10	Maintenance Manager	Country 1, Mill D	+20
Representative 11	Electrical and Automation Manager	Country 1, Mill D	+15
Representative 12	Maintenance Engineer	Country 1, Mill D	+5
Representative 13	Production Manager	Country 1, Mill D	+10
Representative 14	Reliability Engineer	Country 1, Mill C	+20
Representative 15	Production Manager	Country 1, Mill A	+15
Representative 16	Technical Manager	Country 3, Mill E	+10
Representative 17	Production Technician	Country 2, Mill F	+1
Representative 18	Shutdown Manager	Country 1, Mill C	+20
Representative 19	Development Manager	Country 1, Mill C	+20
Representative 20	Reliability Engineer	Country 2, Mill B	+20

The requirement gathering and design process of the preventive maintenance reporting framework was executed following the design thinking process as an iterative development method. A high-level workshop structure to gather the requirements and design the preventive maintenance reporting framework is illustrated in the figure 12.

Although the process and goals may seem straightforward in theory, in practice the process was highly iterative and required a lot of flexibility and adaptability. Agenda and topics of the first workshop was prepared in advance, but second, third and fourth workshops' topics were formed based on the findings in the first workshop. Key info including the agenda of each workshop are presented in the appendices 1-6. The process began with a high-level approach of identifying the success factors that define the preventive maintenance success. From there, the focus delved into examination of the specific questions of one success factor at a time. Once the initial question list was formed, the questions were organized and there

were specific topics found in the scope. Based on those topics, the reporting structure was initially established. The next step involved discussion and brainstorming ideas for the visualizations. Based on the ideas, different kind of visualizations were tested to come up with the most effective visualization to communicate the information for the users. This included a lot of mutual discussion and brainstorming, which finally ended to the result as the preventive maintenance reporting framework. The more detailed description of each workshop is presented after the figure 12.

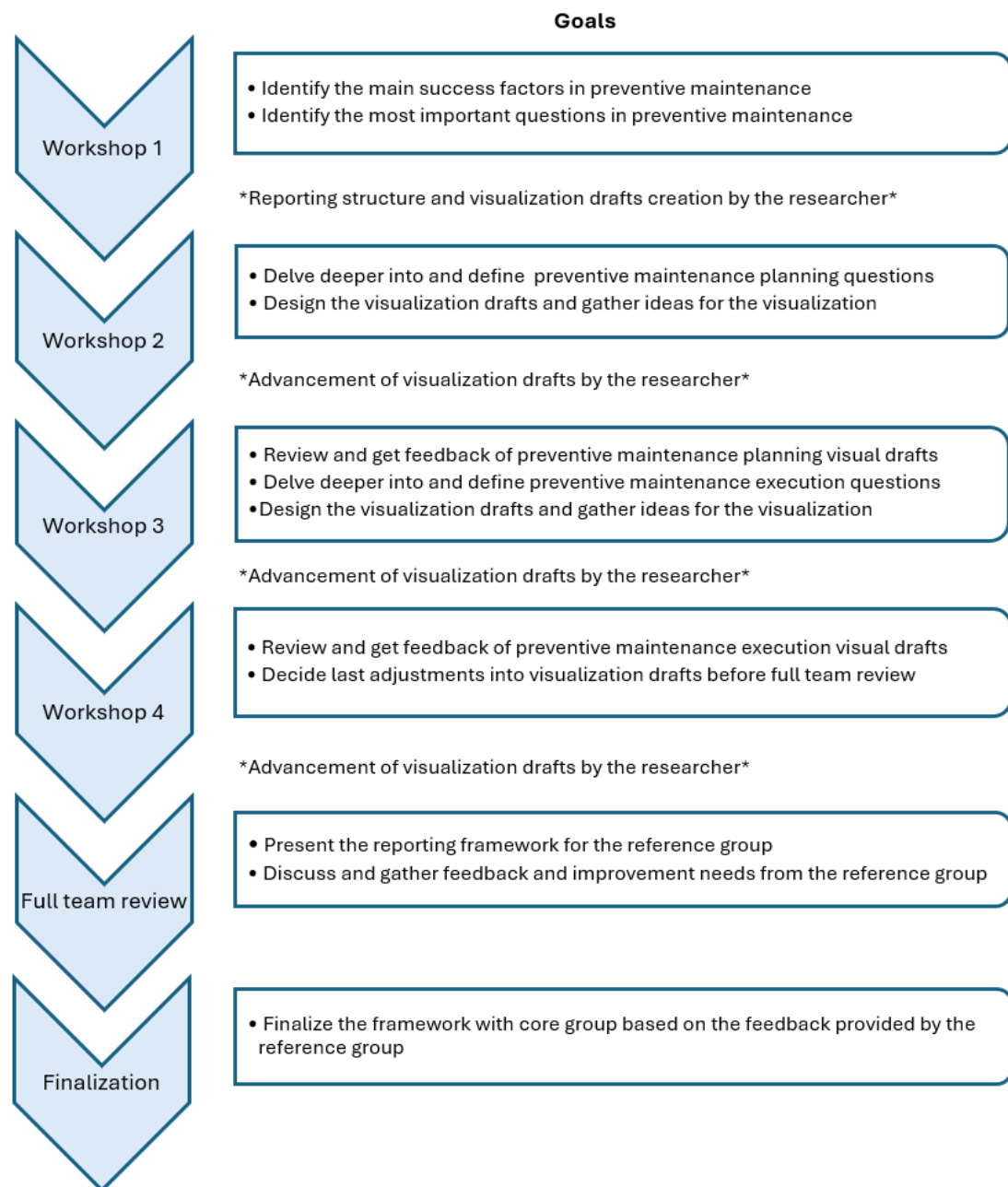


Figure 12: Requirement gathering structure.

Defining and designing the future preventive maintenance reporting framework began with four workshops conducted with the core group of two experienced maintenance specialists. The first workshop began with an introduction of the design process and workshop structure as well as goals and deliverables of the design process. The goal of the workshops was to define the requirements for the preventive maintenance reporting which will be used by the defined main target user groups: maintenance management, maintenance engineers and planners. The targeted deliverables were the visually designed mock-ups of the preventive maintenance reporting with detailed definitions for the actual development process.

The design process itself started with an exploration phase in the first workshop. With the high-level scope and target user groups already defined, the researcher presented an open question for the core group: “What do the target users need to know about preventive maintenance?” The objective of this was to get all the ideas and insights to the table. Researcher documented all the topics and questions to the whiteboard. The first workshop was utilized mainly into this activity. As a result from the first workshop, the main success factors of the preventive maintenance were identified: 1. preventive maintenance planning including the master data, maintenance plan management and maintenance plan history, and 2. preventive maintenance execution according to plan and schedule. For both success factors, initial list of describing questions were identified and additional notes written. The results are shown in the appendices 7 and 8. However, it is important to note that not all identified questions and notes were applied into the final framework as the design thinking process involves multiple iterations. Some of the identified questions were already tackled in the other reporting solutions of the company and some of the questions were dropped when iteration progressed towards the final reporting framework. Between the first and second workshop, the researcher designed the initial reporting structure by dividing the identified success factors, subtopics and describing questions into different pages of the report. Also, few first visualization drafts were designed based on the identified success factors and initial questions. Intention was to generate the initial reporting structure and some initial visualizations to the preventive maintenance planning related questions for the review and feedback.

The second workshop started with reviewing together the results of the first workshop and researcher’s progression on designing the reporting structure as well as the first visualizations in preventive maintenance planning. The review was iterative process of going

through the first version and at the same time re-organizing the report pages, clarifying the defined questions and giving insights about the first visualizations. As the initial scope and layout was reviewed together, the main objective of the second workshop was to delve deeper into first success factor as preventive maintenance planning. The iterative process consisted of the mutual discussion of the defined questions and ideas for the visualizations. The researcher documented these insights as comments and questions and created some quick examples of the visualizations during the discussion to receive immediate feedback of what is working and what is not working. As a result from the second workshop, preventive maintenance planning subtopics and related questions were clarified, initial visualizations were designed and additional ideas for improving the visualization were gathered. Between the second and third workshop, the researcher advanced the visual drafts.

The third workshop was divided into two: review of the iterated preventive maintenance planning visualizations and deeper examination of the second success factor: preventive maintenance execution. The goal was to clarify the most important questions of preventive maintenance execution and gather initial visualization ideas for the reporting. The third workshop followed the same principles of the design process: mutual discussion, gathering and documenting the ideas and insights as well as generating some quick visualizations to support the ideation. As a result from the third workshop, preventive maintenance execution sub-topics, related questions and specific details were defined. In addition, first initial visualizations were designed and ideas for the further design was documented. Between the third and fourth workshop, the researcher continued with designing the visualizations for preventive maintenance execution report pages.

The goal of the fourth workshop was to review the visualization drafts of the preventive maintenance execution, wrap up the past workshops and decide the last adjustments before the full team review. In the beginning of fourth workshop, preventive maintenance execution visualization drafts were presented by the researcher and core group provided the feedback and improvement needs. Thereafter, the past three workshops were wrapped together. Established visualization draft package (later a framework) was reviewed to ensure the consistency of the framework. In addition, the last adjustments to the framework were discussed and determined, enabling the researcher to complete the initial framework for the full team review session.

In the full team review, the core group presented the initial framework for the reference group. Full team review was held in one-hour Teams meeting. Meeting was divided into 20 minutes of mock-up presentation and 40 minutes of mutual discussion. During discussion section, reference group presented questions about the framework and provided their insights and additional requirements that were not covered yet. After the meeting, reference group members also had three days to provide their feedback and improvement points for the core group. Based on the gathered feedback, framework was finalized within the core group in 1 hour Teams meeting. This finalized framework illustrates the preventive maintenance reporting framework which can be utilized as a plan and definition for the actual reporting implementation.

All workshops were held in Teams meetings, and they were recorded. Researcher also acted as a secretary in the workshops sharing the screen whole meeting and writing the notes of the discussion and decisions made during the workshops. Approach in the requirement gathering was based on first defining the most important questions, refining the questions into focus areas and thereafter discussing about possible visualization options to answer the questions based on data. Between the workshops, researcher made visualization proposals to answers to questions defined by the core group and reference group. Visualization proposals were created by using following tools: Microsoft Office Power Point, Microsoft Power BI and collaborative design tool Figma. Visual proposals were always reviewed together with the core group and improved based on their comments.

Before the end-result is being presented, here is one example that explain how the preventive maintenance reporting framework was developed iteratively part by part in practise. Each report page and its visualizations followed the same approach, going through multiple iterations before reaching the final graphical presentation.

Visualizations iterative development always started with the identified questions wanted to be answered by the reporting. In the illustrated example, the initial question was formed as following: “How have the functional locations and equipment been classified (ABC indicator)?” Starting to digest the question, it was discussed in the first workshop that functional locations and equipment are not convenient to visualize as combination. Hence, the visualization was first brainstormed for the functional locations. The first visualization draft answering to the question was a simple bar presented in the figure 13. It shows the number of functional locations per criticality class (ABC indicator).

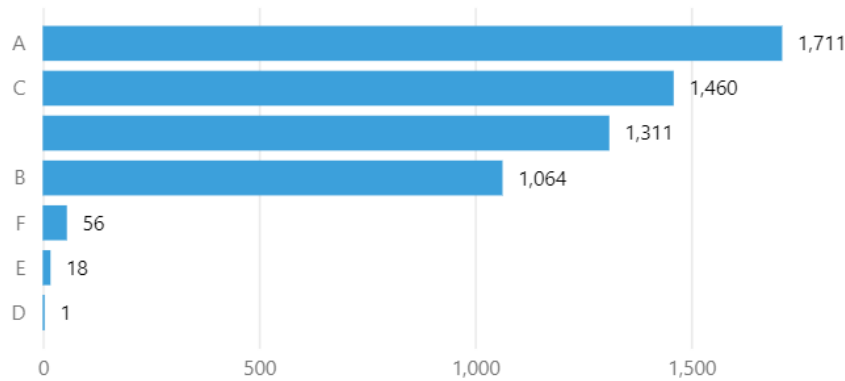


Figure 13: First version of the graph.

This first visualization draft triggered the next question within the core group: “Where is our preventive maintenance focusing? Non-critical or critical functional locations?” This led to idea of combining this information into one graph by having number of functional locations by the criticality class and adding the second bar showing the maintenance plan coverage. The second iteration version is shown in the figure 14. It shows how many functional locations there are per criticality class and how many of those functional locations have maintenance plan defined.

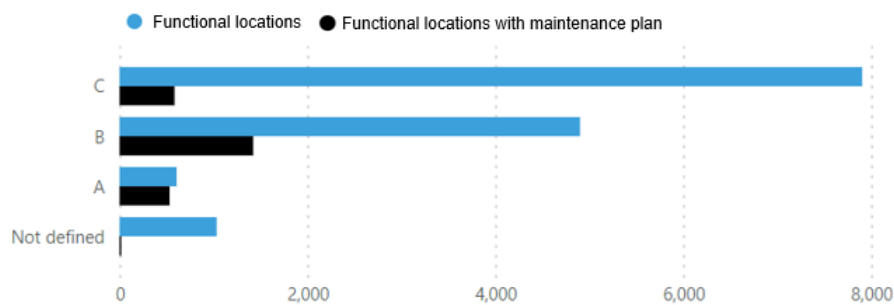


Figure 14: Second version of the graph.

The core group identified that this type of visualization and combination works well. When continuing the list of initially identified questions, one quite similar and related question was found out and discussed in more detail: “What is the BOM coverage (bill of material) on functional locations and equipment?” The discussion resulted into idea of trying to visualize this all together: functional locations by the criticality class, functional locations maintenance plan coverage and functional locations BOM coverage. Another idea was to add switch buttons into the graph so that user can investigate either from maintenance plan coverage or BOM connection coverage point of view and graph would change based on the

button selected. Decision was to proceed with showing the information combined instead of the switch buttons. Also, there was an idea of changing bars to columns. The result of this iteration is being presented in the figure 15 and this figure represents the final version of this graph.

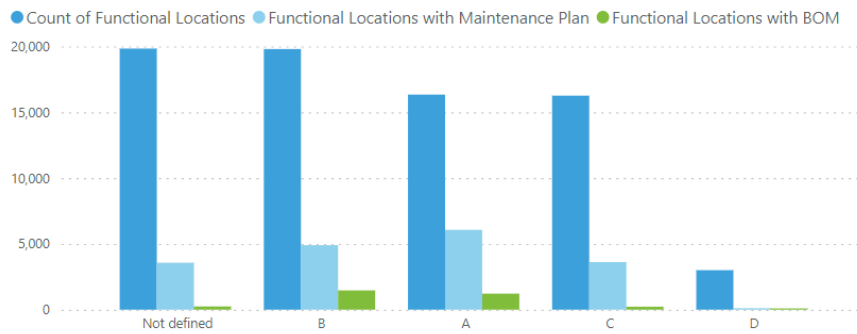


Figure 15: Final version of the graph.

After this final version of the graph, there was also discussion about the need to see how the mills are progressing with the maintenance plan coverage and BOM connection coverage on functional locations and equipment. In the discussion, there was ideas about having own visualizations answering to that and idea of adding the history trend of the progress as a tooltip into the graph that is presented in the figure 15. However, conclusion was to leave these ideas for the future development.

#### 4.4 Preventive maintenance reporting framework

As the results from the workshops and design thinking process, this chapter presents the created preventive maintenance reporting framework. The designed preventive maintenance reporting consists of two areas: planning and execution. The following mock-ups presented in the figures 16–21 represent the reporting framework. In addition to the mock-ups, each of them has a compact documentation giving information about the business need and detailed specifications. This knowledge is giving the guidelines for the future technical implementation of the reporting. Based on these mock-ups and related documentation, company can implement the preventive maintenance reporting in practise.

As presented in the figure 16, preventive maintenance planning section's first page "Master data" provides a comprehensive overview of functional locations and equipment. This page

is used to review the master data, to identify the deficiencies in the master data and improving the master data. The page can be utilized to investigate:

- How does the functional location and equipment hierarchy look?
- How have the functional locations and equipment been classified (ABC indicator)?
- Is there unclassified functional locations and equipment, why?
- What is the maintenance plan coverage on functional locations and equipment?
- Is some e.g. critical asset missing the maintenance plan?
- What is the BOM coverage (bill of material) on functional locations and equipment?

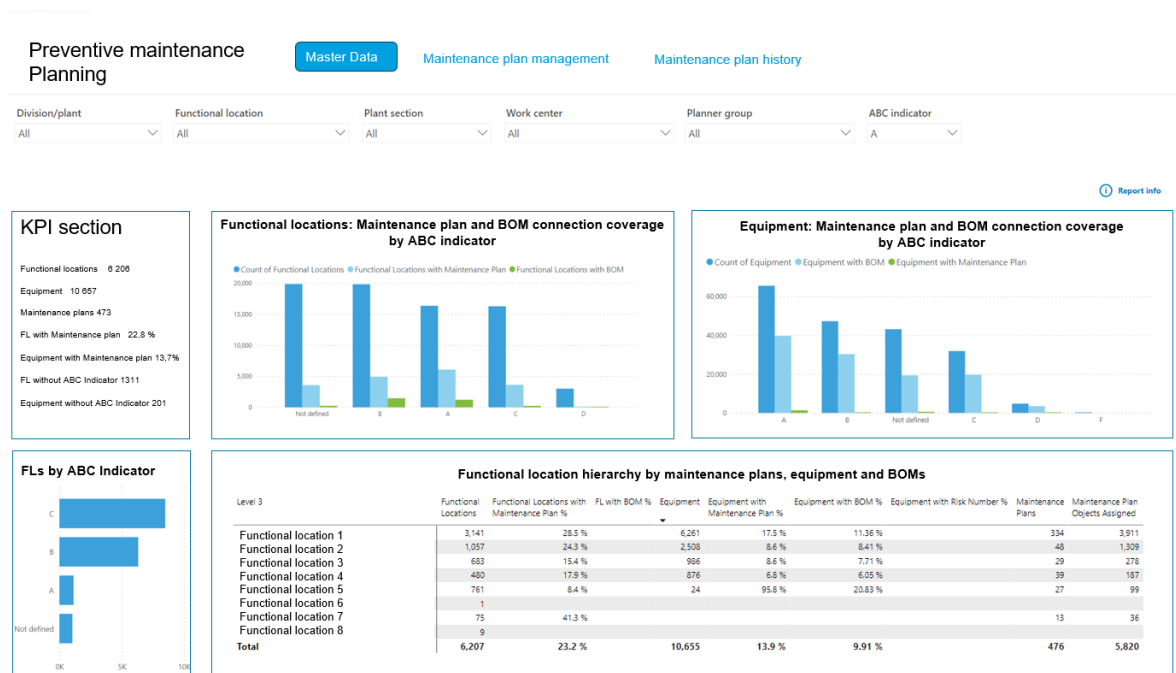


Figure 16: Preventive maintenance – Planning – Master data.

All pages have filters on top of the page. In the preventive maintenance planning pages, user can filter information based on the investigated location (division, plant, functional location, plant section, work center, planner group) as well as the criticality classification indicated by the ABC indicator. In top left corner, the most important KPIs are shown to give a user the baseline of the master data: number of functional locations, equipment, maintenance plans, functional locations with maintenance plan %, equipment with maintenance plan %, functional locations without criticality classification and equipment without criticality classification. On top center and right corner, maintenance plan and bill of material coverage

can be investigated by the functional locations and equipment as well as based on the criticality classification of the assets. Bill of material in this case means that functional location or equipment has identified and linked spare part connected to it. Bottom left corner shows how the functional locations are divided based on the criticality. It also highlights the number of functional locations without the criticality classification. Criticality classification is important in preventive maintenance planning as it helps to prioritize and ensure the most critical assets have accurate preventive maintenance plan. The plant structure is defined based on the functional location and equipment hierarchy. All these previously mentioned master data characteristics can be investigated in the matrix table presented in bottom. It enables drilling down from the plant level through the functional locations into lowest level as the equipment.

Second page named as “Maintenance plan management” illustrated in the figure 17 focusses on the questions: what maintenance plans do we have and how we are managing them? A preventive maintenance package that is never changed, is not adequate since nothing is perfect over time. Different areas in the mill with the same equipment need different approaches. Maintenance plans require regular updates and continuous improvement. It can be seen in the top left graph, where user can see number of new, updated and deleted maintenance plans per month. To see how different teams are making updates, bottom left table has answer to that by showing the number of new, updated and deleted maintenance plans by work center. Top right corner shows the current situation of total maintenance plans by work centers. Moreover, bottom right table shows the list of maintenance plans, and the table is filterable based on the selections on the other graphs. For example, by clicking top left column chart’s last month updated maintenance plans, bottom left table gets filtered and shows those maintenance plans in detail. This kind of functionality and interaction is followed in the whole reporting solution.

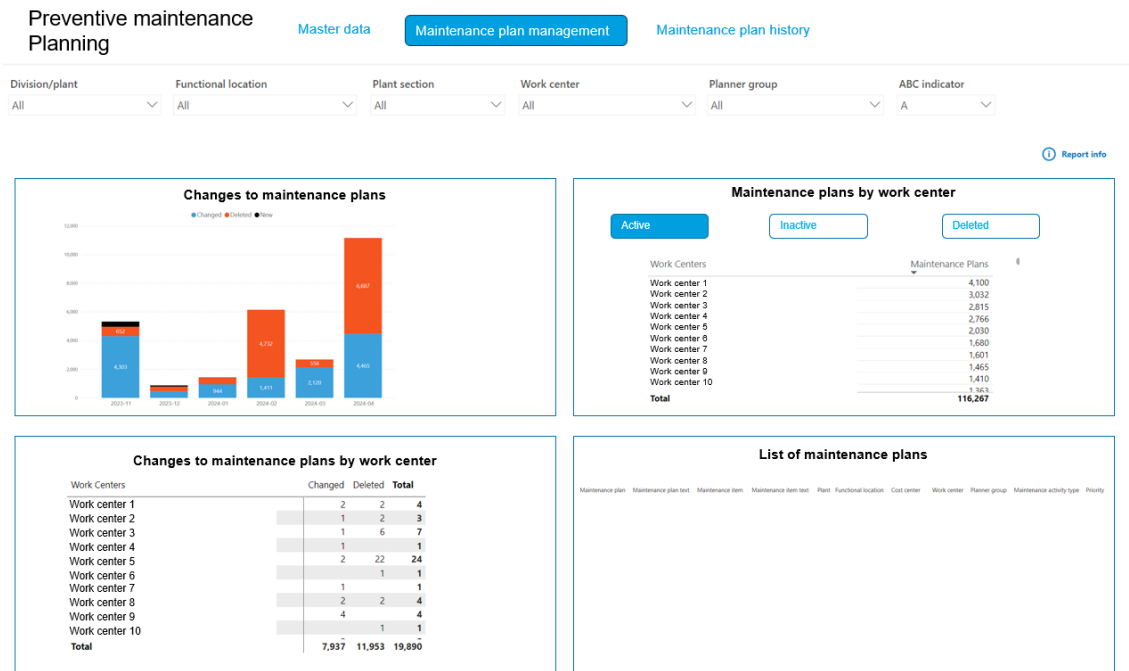


Figure 17: Preventive maintenance – Planning – Maintenance plan management.

Third page as “Maintenance plan history” presented in the figure 18 is defined to give user information about the structure of the maintenance plan setup and maintenance plan’s history. The page is divided into five tables: list of maintenance plans, list of maintenance plan items, history of maintenance plan items, maintenance plan objects and list of notifications or work orders. This page is supportive in nature for seeing the maintenance packages, their settings, history and generated orders and notifications by the maintenance plans. Maintenance plan setup information consists of for example maintenance plan type (e.g. lubrication, condition monitoring etc), location, equipment, responsible team, priority and execution cycle. Tables are meant to be interactive so that user can select one maintenance plan, see the respective maintenance plans items, filter one maintenance plans’ history and see the notifications or work orders generated by the maintenance plan item. In SAP, maintenance plan setup requires navigating in multiple screens and this page gathers the most important information about the maintenance plans into one page for the user.

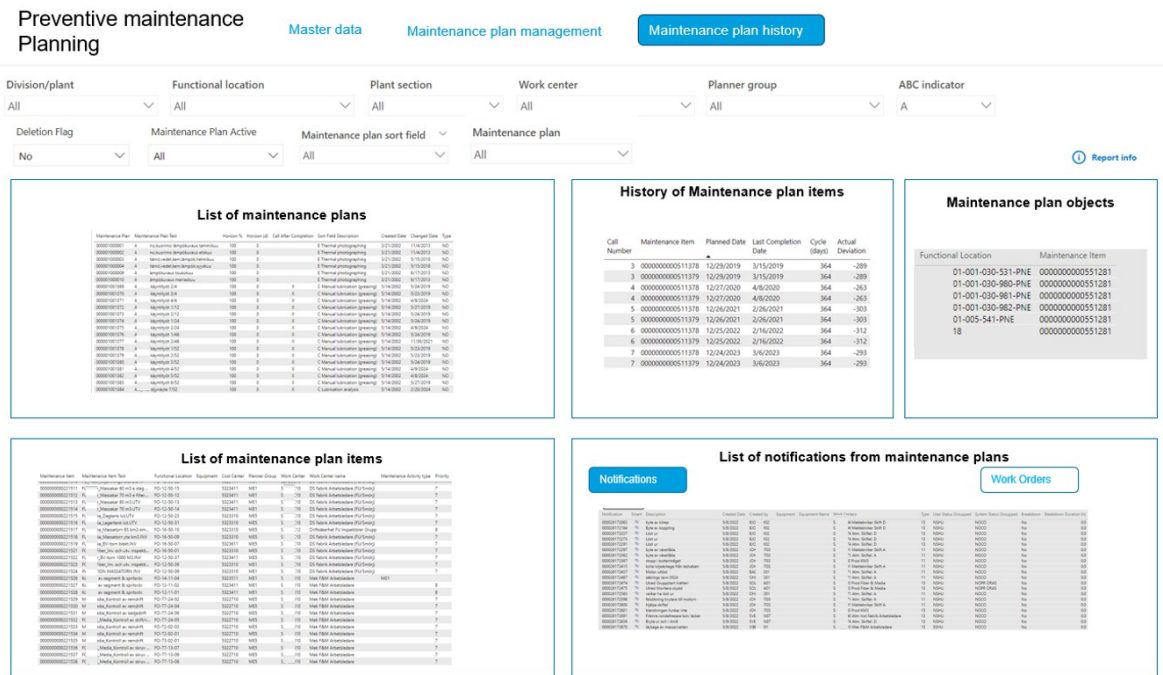


Figure 18: Preventive maintenance – Planning – Maintenance plan history.

Latter part of the report focuses on the second success factor: preventive maintenance execution. This is divided into three pages: main page, orders and notifications.

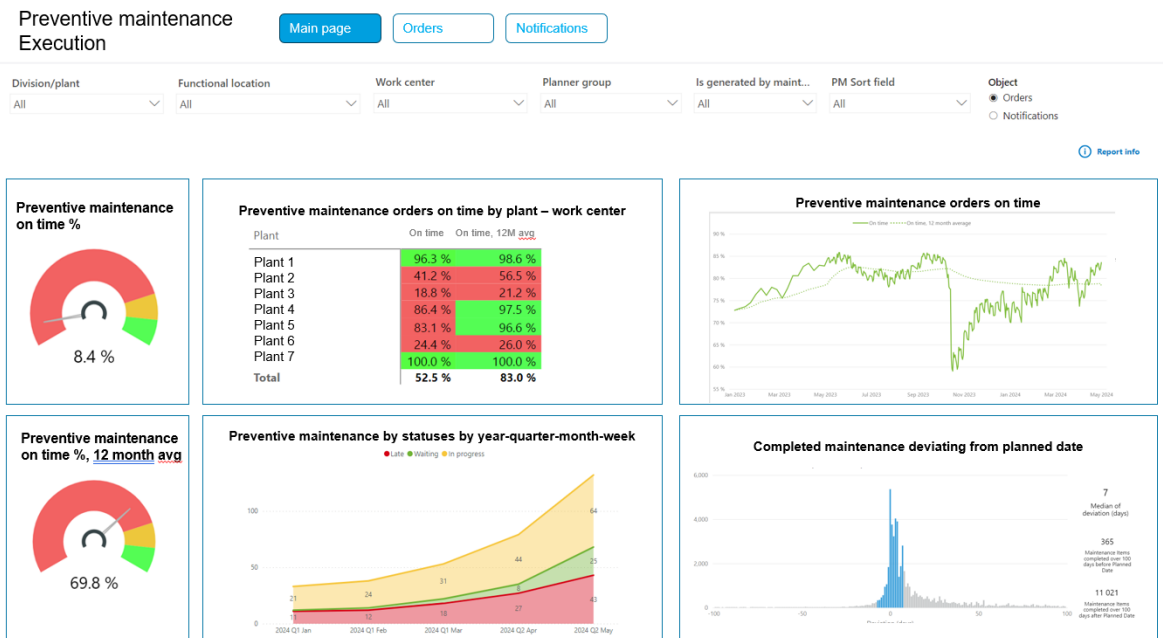


Figure 19: Preventive maintenance – Execution – Main page.

Main page shown in the figure 19 provides an overview how well are we executing the preventive maintenance tasks according to planned schedule? In addition to general location

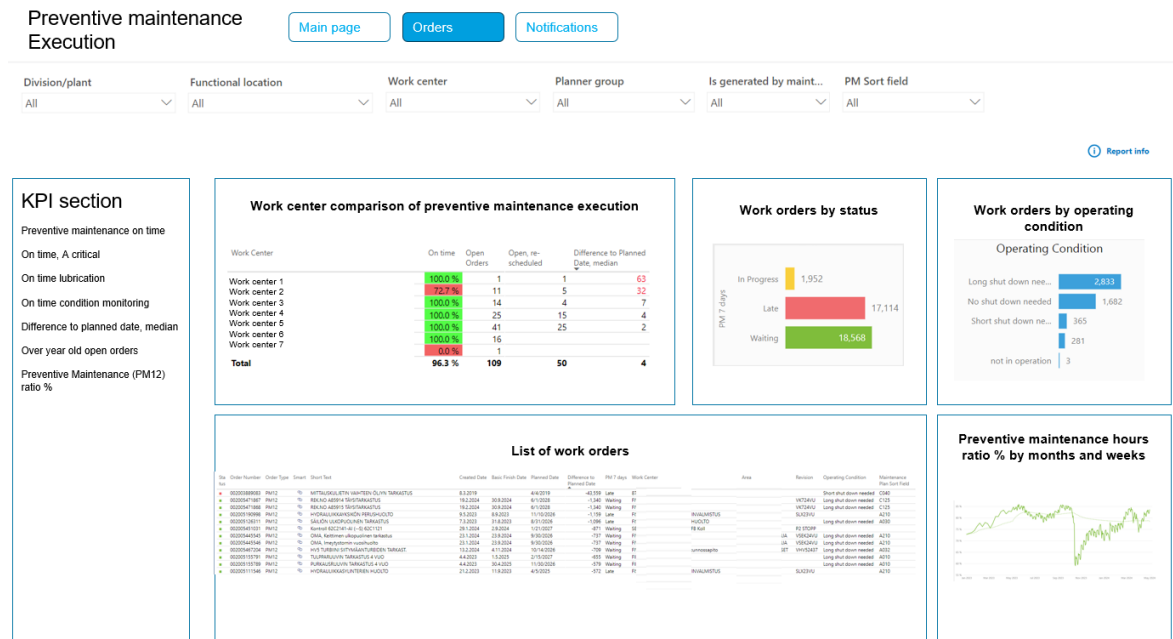
related filtering possibilities, user can filter only maintenance plan generated tasks with “Is generated by maintenance plan” filter and with “PM Sort field” user can focus on different types of preventive maintenance (e.g. lubrication, condition monitoring and so on). Also, user can study either preventive maintenance orders or notifications as company’s plants are using a bit different setup in preventive maintenance.

When going into the actual information provided in the Main page, left side gauge meters show the main KPI of the preventive maintenance execution: preventive maintenance on time % and its 12 months average. It is calculated by dividing open preventive maintenance orders on time by all open preventive maintenance orders. It tells, how much of open preventive maintenance tasks are on time according to preventive maintenance task’s schedule. General target for the preventive maintenance on time as a KPI is 90 %.

At the top center of the page, the matrix table shows the plant and work center comparison in the main KPIs. In this matrix table, user can drill down from plant level to work center level. The line graph in the top right corner shows the preventive maintenance execution development over time: which direction are we going to? In addition to current value of the preventive maintenance on time KPI, there is presented its 12-month average to see longer term development. Stacked line chart in the bottom center of the page shows the different statuses of preventive maintenance tasks development over time. Statuses are waiting (planned date over 7 days in the future), in progress (planned date +-7 days) and late (planned date over 7 in the past). Bottom right graph shows the deviation completed preventive maintenance tasks compared to original planned date, limited into +- 100 days deviation. In addition, there are two values that are showing the outliers to the graph: “Maintenance tasks completed 100 before planned date” and “Maintenance tasks completed 100 after planned date”.

Supportive KPI next to bottom right graph is “Difference to planned date, average” shows the difference between preventive maintenance task completion date and planned date, which should be as low as possible. This is important KPI to follow, because it reveals if the preventive maintenance work is often or mostly re-scheduled. Preventive maintenance on time KPI is calculated based on defined start date of the work order. However, this start date can be changed by the users. It means that preventive maintenance on time KPI can look relatively good. In comparison, work order’s planned date, which is coming from the maintenance plan, cannot be changed. This is the reason why difference to planned date

(average) KPI is important next to the preventive maintenance on time KPI. If difference to planned date is showing a high number as a significant deviation, it is crucial to raise a question why.



creating good competition between the work centers. Selected measures for the comparison are on time %, number of open orders, re-scheduled open orders and difference to planned date (average). In the next bar chart user can see number of open preventive maintenance tasks in different statuses and pinpoint for example late tasks. Top right graph is showing the open preventive maintenance tasks based on operating condition (no shutdown needed, short shutdown needed, long shutdown needed). In the bottom, user can see task list and is able to filter the list based on the selections in the filters and other graphs. In addition to these shared information between these two pages, orders page shows the share of preventive maintenance hours of total maintenance hours. Notifications as the last page of the report shown in the figure 21, is showing the same information than the previous “Orders” page, but data is coming from the SAP PM notifications instead of work orders.

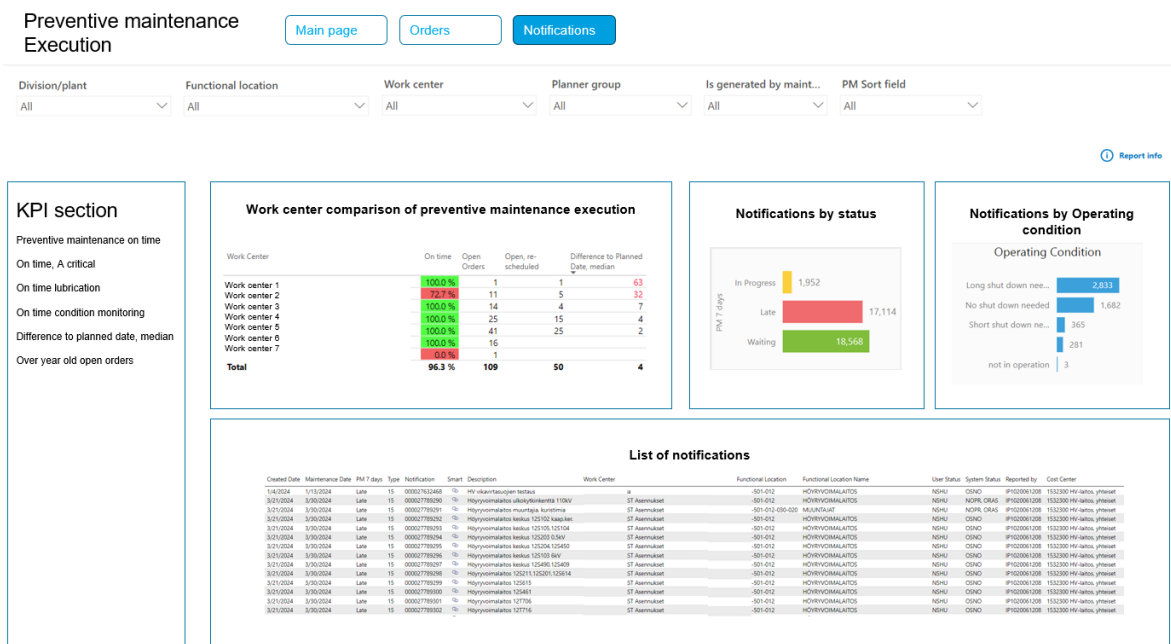


Figure 21: Preventive maintenance – Execution – Notifications.

## 5 Conclusions

This chapter concludes the study by presenting the research objective and key findings. In addition, the chapter discusses about the reliability and limitations of the study. Finally, the chapter presents the suggestions for the future research.

### 5.1 Summary

The study consisted of two parts: literature review and action research. Result of the study was achieved by combining the information of these two. Literature review provided the basic understanding to the study content: maintenance and especially preventive maintenance in the industry, maintenance information systems, reporting and role of business intelligence in the context.

Action research performed in the research company delved into the company's needs and requirements in preventive maintenance reporting. Workshops conducted with the maintenance representatives of the research company played a pivotal role in the action research. Workshops were utilized to gather and define the requirements and design the preventive maintenance reporting framework through design thinking methodology. Initial preventive maintenance reporting framework was designed in the four two-hour workshops with research company's two key maintenance representatives. Researcher as a facilitator led the workshops and helped the representatives to come up with the visualized mock-ups illustrating the preventive maintenance reporting framework. To prevent a narrow perspective for the needs, the prepared mock-ups were presented for the reference group of 20 people around the company from different countries, divisions and plants. Based on the reference group's feedback, preventive maintenance reporting framework was finalized, and it presents the result of this study.

### 5.2 Answering the research questions

The objective of this research was to develop a framework for preventive maintenance reporting that supports research company's industrial plants to manage and improve their

preventive maintenance operations. Intention was to create a framework which can be used as a basis for the practical implementation of the preventive maintenance reporting with business intelligence and data analytics tools in the research company. To support the objective of the study, two research questions were formed.

- RQ1: What are the key success factors in preventive maintenance?

At a high level, this study identified three key success factors for the preventive maintenance which are planning, scheduling and schedule compliance. Identified success factors found in theoretical and empirical parts slightly differ by their names but in practise, they are aligned. Theoretical part identified these success factors namely as planning, scheduling and schedule compliance. On the other hand, empirical part combined planning and scheduling into one success factor and schedule compliance was named as execution. First, effective planning of the preventive maintenance program is crucial. This means understanding the items and their characteristics, defining the criticality of the items, failures modes and impacts. In addition to comprehensive understanding of the items, planning includes the history analysis of the item failures, spare part consumption and item manufacturer's instructions. Second, in addition to planning, scheduling plays a crucial role in ensuring that the required preventive maintenance actions are carried out at the right time. It is important to find a balance between preventing failures and avoiding unnecessary costs. Therefore, finding an appropriate frequency is in a key role. Third, schedule compliance means completing the defined preventive maintenance plans within the defined timeframe. The starting point for the future preventive maintenance reporting should be focusing on these success factors' performance measurement and support.

- RQ2: What are the research company's requirements for the preventive maintenance reporting?

Chapter 4 focused on answering to the second research question. It opened the background and research company's high-level need for the study, explained the requirement gathering and design thinking process applied through the workshops and finally presented the concrete result of the study illustrated by the visualized mock-ups. Research company's requirements for the preventive maintenance reporting are aligned with the theoretical findings about the success factors and some of the key performance indicators. The reporting has been divided into two main topics: preventive maintenance planning and preventive

maintenance execution. Preventive maintenance planning focuses on the master data, maintenance plan management and maintenance plan history as the sub-topics. Preventive maintenance execution focuses on the maintenance plans execution measurement including the schedule compliance. In the execution, the designed reporting also provides a detailed analysis of the preventive maintenance tasks and support in their management. All in all, the research company requires a comprehensive preventive maintenance reporting which provides a visibility, performance measurement and detailed analysis possibilities which help to enhance and optimize the preventive maintenance actions in the mills across the company. This preventive maintenance reporting gathers and combines the most important information to manage preventive maintenance actions in the mills and works as a tool to enhance the operations. Common reporting system used across the company also provides an overview of the entire company's performance, enables comparison of the mills and identify the deficiencies and improvement needs.

Table 4 shows the main topics and findings discussed in this study comparing the theoretical and empirical findings in brief. As a summary, theoretical and empirical findings are well aligned. The difference is that in the existing literature presented the preventive maintenance and reporting related topics in more high level and in the empirical research in the company, discussion got a lot more detailed providing the more practical understanding of the preventive maintenance reporting and need for it in practical environment.

Table 4: Theory and empirical study comparison.

	Theory	Empirical
<b>Success factors</b>		
Planning	x	x
Scheduling	x	x
Schedule compliance	x	x
<b>Key performance indicators</b>		
Criticality classification of items	x	x
Maintenance plan coverage		x
Bill of material coverage		x
Preventive maintenance compliance	x	x
Share of preventive maintenance	x	x
Mean time between failure (MTBF)	x	x
Mean time between repair (MTBR)	x	x
Preventive maintenance cost per equipment	x	
Non-quality production volume	x	
Production loss	x	
Difference to planned date (avg)		x
<b>Maintenance system's own reporting</b>		
Weak usability	x	x
Limited content	x	x
Limited customization possibilities	x	x
<b>Additional reporting with business intelligence</b>		
Need for customized reporting	x	x
Used in performance measurement	x	x
Easy and simply visualisation	x	x
Drill down needs	x	x

### 5.3 Limitations and future research suggestions

Reliability of the study can be seen good when evaluating it in the research company's context. Study was completed in strong collaboration with the research company's personnel. The results present the research company's requirements and vision for the preventive maintenance reporting. Workshop plan and implementation supported the reliability in the research company context. Of course, the results were highly impacted by the selection of research participants: key representatives and the reference group. However, overall participant group was selected with the aim of having enough variety in the participant group: different countries, divisions, mills and maintenance roles.

Impact of the research for the research company can be seen significant. However, in the wider context, the impact may not be as significant as this action research strongly focuses on the research company context and its needs. Nevertheless, the study can offer valuable

ideas and examples for the wider audience: what topics to include in the preventive maintenance reporting to effectively measure and improve preventive maintenance performance.

There are a lot of possibilities for the future research, both in general and in the research company's context. Workshops and discussion with the company's personnel generated development ideas which could not be dealt in the strict scope of this study. At the same time, these topics can be seen as limitations of this study, and further development and research needs for the future. One essential topic for the future development of the reporting was visibility of top functional locations and equipment generating the most failures and maintenance work. Other important future development need is a detailed analysis and reporting of the malfunctions: which type of malfunctions are occurring, impacted items and identified reasons for the malfunctions. These topics are closely related to the overall preventive maintenance as one part of the comprehensive maintenance reporting system.

In the future, once the preventive maintenance reporting system has been implemented according to the defined framework and used across the company for some period, it would be beneficial to conduct a post-implementation audit. This audit would focus on finding how the result serves the personnel across the company and what further development needs they see. When personnel begin to use the solution in practice, they will gain insights what other aspects need to be measured. This could include for example the forecasting needs in addition to analysing past and present.

The result of this study as the preventive maintenance reporting can be seen as conventional business intelligence solution. In the scope of results cannot be seen any advanced analytics needs and topics. The exploration of advanced analytics solutions should be included as a topic for future development and research endeavors.

## References

- Ahmed, S. & Mohd Asraf, R. 2018. The Workshop as a Qualitative Research Approach: Lessons Learnt from a “critical Thinking Through Writing’ Workshop. *The Turkish Online Journal of Design, Art and Communication*. September 2018 Special Edition, p. 1504–1510.
- Anttila, P. 1996. Tutkimisen taito ja tiedonhankinta: Taito-, taide- ja muotoilualojen tutkimuksen työvälineet. 2. p. Helsinki: Akatiimi.
- Bevilacqua, M. & Braglia, M. 2000. The analytic hierarchy process applied to maintenance strategy selection. *Reliability Engineering & System Safety*. Vol. 70, No. 1. p. 71–83.
- Burstein, F. & Holsapple, C.W. 2008. Handbook on Decision Support Systems 2. International Handbooks on Information Systems. © Springer-Verlag Berlin Heidelberg.
- Carr, W. & Kemmis, S. 1986. Becoming critical: Education, Knowledge and Action Research. Victoria, Deakin University. p. 249.
- Caverion 2021. Kuinka rakennat oikein mitoitettun teollisuuden ennakkohuolto-ohjelman? Available at: <https://www.caverion.fi/blogi/teollisuus/teollisuuden-ennakkohuolto-ohjelma/> [Accessed 08 August 2024].
- Clarke, Y. C. 2020. Design Thinking. American Library Association. p. 59.
- Coetzee, J. L., 2004: Maintenance. Trafford Publishing, Victoria.
- Cohen, L. & Manion, L. 1980. Research Methods in Education. Croom Helm Ltd., Educational Research Methodology, London.
- Darsø, L. 2001. Innovation in the making. 1<sup>st</sup> edition. Samfundslitteratur.
- Davison, R. M., Martinsons, M. G., & Kock, N. 2004. Principles of Canonical Action Research, *Information Systems Journal* 14, p. 65–86.
- Deepak Prabhakar, P. & Dharmaraj, A. 2018: Modern Plant Maintenance and Reliability Management Methods – A review. *International Journal of Mechanical and Production Engineering Research and Development*. Vol. 8, Issue 3, Jun 2018, p. 791–802.

- Duffuaa, S. O. & Raouf, A., 2015: Planning and Control of Maintenance Systems – Modelling and Analysis. Second Edition. © Springer International Publishing Switzerland. p. 361.
- Elliott, J. 1991. Action Research for Educational Change. Buckingham, Open University Press.
- Few, S. 2006. Information Dashboard Design – The Effective Visual Communication of Data. O’Reilly. p. 223.
- Gruber, A., Yanovski, S. & Ben-Gal, I. 2020. Condition-based maintenance via a targeted Bayesian network meta-model. Systems engineering in the fourth industrial revolution. p. 203–226.
- Järviö, J. & Lehtiö, T. 2012. Kunnossapito – tuotanto-omaisuuden hoitaminen. 5th edition. Promaint Helsinki.
- Kelly, A. 2006. Strategic maintenance planning. Elsevier Science & Technology.
- Kister, T. C. & Hawkins, B. 2006. Maintenance Planning and Scheduling: Streamline your organization for a Lean Environment. Elsevier Science & Technology. p. 351.
- Kłos, S. & Patalas-Maliszewska, J. 2013. The Impact of ERP on Maintenance Management. *Management and Production Engineering Review*, 4(3), p. 15–25.
- Ku, S. & Kim, C. 2018. Development of a model for maintenance performance measurement. A case study of a gas terminal. *Journal of Quality in Maintenance Engineering*. Vol. 26, No. 1, 2020. p. 69–86.
- Laine, H. S. 2010. Tehokas kunnossapito - tuottavuutta käynnissäpidolla. KP-Media Oy. Kerava: Savion Kirjapaino Oy.
- Larson, D. & Chang, V. 2016. A review and future direction of agile, business intelligence, analytics and data science. *International Journal of Information Management*. Vol. 36. 2016. p. 700–710.
- Lea, B-R., Yu, W-B. & Min, H. 2018. Data visualization for assessing the biofuel commercialization potential within the business intelligence framework. *Journal of Cleaner Production*. Vol 188. 2018. p. 921–941.

- Luchs, M. G., Swan, S. & Griffin, A. 2016. Design Thinking: New Product Development Essentials from the PDMA. John Wiley & Sons, Incorporated. p. 490.
- Lundgren, C., Bokrantz, J. & Skoogh, A. 2020. Performance indicators for measures the effects of Smart Maintenance. *International Journal of Productivity and Performance Management*. Vol. 70, No. 6, 2021. p. 1291–1316.
- Maggard, B. & Rhyne, D. 1992. “Total productive maintenance: a timely integration of production and maintenance”. *Production and Inventory Management Journal*. Vol. 33, Fourth Quarter, p. 6–10.
- Manzini, R., Regattieri, A., Pham, H. & Ferrari, E. 2010. Maintenance for Industrial Systems. Springer Dordrecht Heidelberg London New York.
- Martinsuo, M. & Kärri, T. 2017. Teollinen internet uudistaa palveluliiketoimintaa ja kunnossapitoa. Kunnossapitoyhdistys Promaint ry.
- McNiff, Jean. 2013. Action research: principles and practice.
- Mikkonen, H., Miettinen J., Leinonen, P., Jantunen, E., Kokko, V., Riutta, E., Sulo, P., Komonen, J., Lumme, V.E., Kautto, J., Heinonen, K., Lakka, S., Mäkeläinen, R. 2009. Kuntoon perustuva kunnossapito. KP-Media Oy. Kerava: Savion Kirjapaino Oy.
- Miller, G. J., Bräutigam, D. & Gerlach, S. V. 2006. Business Intelligence Competency Centers: A Team Approach to Maximizing Competitive Advantage. SAS Institute Inc., Cary, North Carolina, USA.
- Mobley, R. K. 2002. An Introduction to Predictive Maintenance. 2<sup>nd</sup> ed. Amsterdam: New York: Butterworth-Heinemann.
- Mobley, R. K. 2004. Maintenance fundamentals. 2<sup>nd</sup> ed. Amsterdam: Butterworth-Heinemann.
- Nyman, D. & Levitt, J. 2001: Maintenance Planning, Scheduling and Coordination. Industrial Press.
- Ohring, M. & Kasprzak, L. 2015. Reliability and Failure of Electronic Materials and Devices. 2nd edition. Elsevier. p. 704.

- Ørngreen, R. & Levinsen, K. T. 2017. Workshops as a Research Methodology. *Electronic Journal of E-Learning*.
- Parida, A. & Kumar, U. 2006: Maintenance performance measurement MPM issues and challenges. *Journal of Quality in Maintenance Engineering*, 2006–07, Vol. 12 (3), p. 239–251.
- Parida, A., Kumar, U., Galad, D. & Stenström, C. 2015. “Performance measurement and management for maintenance: A literature review,” *Journal of Quality in Maintenance Engineering*, Vol. 21, No. 1, p. 2–33.
- Quintana, R., Leung, M., Villalobos, R. & Michael, G. 2009. Corrective maintenance through dynamic work allocation and pre-emption: case study and application. *International Journal of Production research*. Vol. 47, (13), p. 3539–3557.
- Runkler, T. A. 2016. *Data Analytics, Models and Algorithms for Intelligent Data Analysis*. Springer Fachmedien Wiesbaden.
- Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. 2011. Action Design Research. *MIS Quarterly*, 35 (1), p. 37–56.
- Selvik, J. T., Stanley, I. & Abrahamsen, E.B. 2000. SMART Criteria for Quality Assessment of Key Performance Indicators Used in the Oil and Gas Industry. *International Journal of Performability Engineering*. Vol. 16, No. 7, July 2020, p. 999–1007.
- SFS-EN 13306. 2017:en. Maintenance – Maintenance terminology. Helsinki: Finnish Standards Association SFS.
- SFS-EN 15341. 2019:en. Maintenance – Maintenance Key Performance Indicators. Helsinki: Finnish Standards Association SFS.
- Sigsgaard, K., Agergaard, J., Mortensen N. & Soleymani, I., 2021: Data-Driven Systematic Evaluation of Preventive Maintenance Performance. *Annual Reliability and Maintainability Symposium (RAMS)*, 2021, p. 1–7.
- Simoës, J. M. 2011. A literature review of maintenance performance measurement - A conceptual framework and directions for future research. *Journal of Quality in Maintenance Engineering*. Vol 12. No. 2, 2011. p. 116–137.

- Smith, D. J. 2022: Reliability, Maintainability and Risk - Practical Methods for Engineers. 10th edition. Elsevier. p. 492.
- Snyder, H. 2019. Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*. Vol 104, November 2019, p. 333–339.
- Sørensen, J. D. & Sørensen J. N. 2011. Wind Energy Systems - Optimising Design and Construction for Safe and Reliable Operation. Woodhead Publishing. p. 585.
- Syamsundar, A., Naikan, V. & Wu, S. 2021. Estimating maintenance effectiveness of a repairable system under time-based maintenance. *Computers and industrial engineering*, 2021–06, Vol. 156, 107278.
- Vallurupalli, V. & Bose, I. 2017. Business intelligence for performance measurement. A case-based analysis. Indian Institute of Management Calcutta, India. *Decision Support Systems*. Vol. 111, July 2018. p. 72–85.
- Väänänen, M., Nieminen, T. & Jokinen, J. 2003. Kunnossapidon tietojärjestelmät – osa yrityksen tiedonhallintaa. Hämeen ammattikorkeakoulu. Julkaisu A: 1/2003. Saarijärven Offset Oy, Saarijärvi.
- Waeyenbergh, G. Pintelon, L. 2002. A framework for maintenance concept development. *International journal of production economics*. Vol. 77, (3), p. 299–313.
- Zou, G., González, A., Banisoleiman, K. & Faber, M. 2019. An integrated probabilistic approach for optimum maintenance of fatigue-critical structural components. *Marine Structures*, 2019–11, Vol. 68

## Appendix 1. Key info of the first workshop.

### Workshop 1

- Participants: researcher and core group
- Agenda
  - Introduction to the design process and workshop structure
  - Goals and deliverables of the design process
  - Identification of the preventive maintenance success factors
  - Identification of the most important questions related to success factors

## Appendix 2. Key info of the second workshop.

### Workshop 2

- Participants: researcher and core group
- Agenda
  - Reviewing the results and progress from the first workshop
  - Delving deeper into the first identified success factor: preventive maintenance planning
  - Discussing and refining the defined questions and ideas for visualizations
  - Designing initial visualizations and documenting ideas for further design

### Appendix 3. Key info of the third workshop.

#### Workshop 3

- Participants: researcher and core group
- Agenda
  - Reviewing and iterating on the preventive maintenance planning visualizations
  - Examining the second success factor: preventive maintenance execution
  - Clarifying important questions and gathering visualization ideas
  - Designing initial visualizations and documenting ideas for further design

Appendix 4. Key info of the fourth workshop.

#### Workshop 4

- Participants: researcher and core group
- Agenda
  - Reviewing the visualization drafts for preventive maintenance execution
  - Wrapping up the past workshops and making final adjustments

## Appendix 5. Key info of the full team review.

### Full team review

- Participants: researcher, core group and reference group
- Agenda
  - Presentation of the initial reporting framework by core group
  - Mutual discussion and feedback gathering

## Appendix 6. Key info of the finalization meeting.

### Finalization meeting

- Participants: researcher and core group
- Agenda
  - Addressing questions, insights, and additional requirements provided by the reference group in the full team review
  - Finalizing the reporting framework based on feedback and improvement points

## Appendix 7. Preventive maintenance planning – initial notes and question list.

- Overview of our functional locations
  - What is the structure of our assets (functional locations & equipment)?
  - How many functional locations we have?
  - What is the criticality of our functional locations (ABC Indicator)?
  - How many maintenance plans we have (active, deletion flagged)?
  - How many functional locations without maintenance plans based on criticality?
  - How many equipment without spare parts (BOM link) based on criticality?
  - Where does our preventive maintenance focus (non-critical or critical assets)?
- Overview of our equipment
  - How many maintenance plans we have in (A class) equipment?
  - What is the criticality of our equipment (ABC Indicator)?
  - How many equipment without maintenance plans based on criticality?
  - How many equipment without spare parts (BOM link) based on criticality?
- How often we update our master data?
  - Maintenance plans (maintenance items, task lists, object lists)
  - Equipment classification
- MTBR & MTBF
- TOP lists: notifications and work orders, malfunctions
  - How many of the immediate work orders are on equipment that we don't have maintenance plan?
  - Do we have immediate notifications on equipment that we have maintenance plans?

## Appendix 8. Preventive maintenance execution – initial notes and question list.

- How are we executing preventive maintenance work on the scheduled time?
- How the preventive maintenance on time has developed over time?
- Are we lacking in preventive maintenance work?
- How are the condition monitoring and lubrications rounds executed on time as the two important preventive maintenance categories?
- How many preventive maintenance work orders are overdue and what are those? What work orders were executed too early? On time/late/early
- Which preventive maintenance works are already late, what are the priorities?
- Comparison of work centers in preventive maintenance?
- What is the ratio between preventive maintenance and corrective maintenance? (hours, work orders, cost)?
- How much is spent for the preventive maintenance?
- How preventive maintenance work is distributed over the year?
- How effective is our preventive maintenance?
- How many issues we have identified in the preventive maintenance rounds?
- Which crew performs the most preventive maintenance work?